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ENGINEERING:

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See Advertisement, page 26. 9052

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TENDERS.

SWANSEA HARBOUR TRUST.

The Swansea Harbour Trustees invite

Tenders for the Repair of certain FERRO-CONCRETE QUAYS in their King's Dock, by means of the Cement Gun. The quays may be inspected, and further particulars of the nature of the repairs to be executed may be obtained, on application to the Trustees' Engineer, Mr. A. C. SCHENK, M.I.C.E., Harbour Offices, Swansea.

Tenders, marked "Repairs to Quays," should be delivered to the undersigned not later than Ten a.m. on Friday, the 24th March, 1922.

The Trustees do not bind themselves to accept the lowest or any Tender.

TALFOURD STRICK, Clerk.

Harbour Offices, Swansea.
25th February, 1922. T 571

CITY OF LEICESTER. WATER DEPARTMENT.

PUMPING MACHINERY.

The Water Committee of the City of Leicester invite

Tenders for the Supply and ERECTION of OIL or GAS ENGINES and PUMPS for pumping continuously 50,000 gallons of water per hour through about 70,000 feet of 14 inch diameter pipes against a static head of 123 feet.

General Conditions, Specification and Form of Tender may be obtained from G. T. EDWARDS, Esq., M.Inst.C.E., Water Engineer and Manager, Bowling Green Street, Leicester, on deposit of a cheque value five pounds which will be returned on receipt of a *bona fide* Tender, and the return of all documents supplied.

Tenders endorsed "Pumping Machinery" are to be delivered to the undersigned in a sealed envelope on or before Ten a.m. on April 10th next.

The Committee do not bind themselves to accept the lowest or any Tender.

G. T. EDWARDS, M.Inst.C.E., Engineer and Manager.

Waterworks Office, Bowling Green Street, Leicester. T 122

URBAN DISTRICT COUNCIL OF CHEADLE AND GATLEY.

ELECTRICITY SCHEME.

TENDERS FOR MAINS, ETC.

The Urban District Council of Cheadle and Gatley invite

Tenders for Extra High PRESSURE, MEDIUM PRESSURE and LOW PRESSURE MAINS and STREET LIGHTING ACCESSORIES. Copies of Specification with Form of Tender and General Conditions can be obtained of the Council's Engineer, Mr. C. H. WORDINGHAM, C.B.E., M.Inst.C.E., either from 11, Mosley Street, Manchester, or 7, Victoria Street, Westminster, London, S.W. 1. A complete set of the drawings referred to in the Specification can be seen between the hours of Ten a.m. and Four p.m. at the same addresses.

A deposit of Three Guineas in respect of the Specification is required, which sum will be refunded within one month of the date of the adjudication upon the Tenders, provided that a *bona fide* Tender be submitted and not withdrawn.

A duplicate copy of the Specification and General Conditions will be supplied on payment of One Guinea, which sum is not returnable. A complete set of drawings will be supplied on payment of the sum of One Guinea, which sum also is not returnable.

Tenders enclosed in an envelope sealed with wax and clearly endorsed "Tender for Mains, Cheadle," must be addressed to the undersigned, Clerk to the Urban District Council of Cheadle and Gatley, Council Offices, Cheadle, Cheshire, and must be delivered not later than Noon on the 3rd April, 1922.

The Council do not bind themselves to accept the lowest or any Tender.

By Order,
JOHN H. JOHNSON, Clerk to the Council,

Council Offices, Cheadle, Cheshire.
7th March, 1922. T 661

THE HIGH COMMISSIONER FOR INDIA

is prepared to receive

Tenders for the Supply of:—
CABLE, Electric.
PIPES, Cast-iron.

Forms of Tender may be obtained from the Director-General, India Store Department, Belvedere Road, Lambeth, S.E. 1, and Tenders are to be delivered at that Office not later than Two o'clock p.m. on Friday the 31st March, 1922.

T. RYAN, Director-General.
T 753

DEPARTMENT OF STATE RAILWAYS.

NOTICE.

Tenders are Invited for the SUPPLY of 25 UNDERFRAMES for Bogie Carriages.

Specifications and Drawings may be obtained against payment of £3 from Messrs. C. P. SANDBERG, 40, Grosvenor Gardens, London, S.W. 1.

Sealed Tenders with the inscription "Tender for the supply of Underframes for Bogie Carriages 2465," must be forwarded to the undersigned at whose office in the City of Bangkok, Siam, they will be received up to Two p.m. on the 1st day of August, 1922, at which place and hour the Tenders will be publicly opened and read.

Right is reserved to reject any or all Tenders and to accept any Tender which in the opinion of the undersigned is to the best interests of the Siam State Railways.

GENERAL PURACHATRA, Commissioner General of State Railways.
Department of State Railways, Bangkok, 3rd February, 1922. T 737

BELFAST HARBOUR.

THE BELFAST HARBOUR COMMISSIONERS are prepared to receive

Tenders for the Construction OF A JETTY AND DOLPHINS IN REINFORCED CONCRETE, on the Eastward Side of the New Oil Berth, Musgrave Channel, Co. Down, all in accordance with Drawings which may be seen at the Office of the Harbour Engineer, Mr. T. S. GILBERT, M.Inst.C.E., from whom copies of the Conditions of Contract, Draft Specification, and form of Tender may be obtained.

Tenders must be made on the form provided for the purpose and must be enclosed in a sealed envelope, endorsed "Tender for Jetty and Dolphins," addressed to the General Manager and Secretary, Belfast Harbour Commissioners, and delivered to him not later than Monday, the 3rd April, 1922.

The Commissioners do not bind themselves to accept the lowest or any Tender.

D. J. OWEN, General Manager and Secretary.

Harbour Office, Belfast.
11th March, 1922. T 720

BOMBAY, BARODA & CENTRAL INDIA RAILWAY COMPANY.

The Directors are prepared to receive up to noon on Wednesday, 5th April,

Tenders for the Supply of:

1. Crank and Straight Axles for Locos.
2. Copper Firebox Plates.
3. Helical and Volute Springs.
4. Laminated Springs.
5. Steel Boiler Tubes.
6. Tyres for Locomotives.

Tenders must be made on forms, copies of which, with specification, can be obtained at these offices on payment of 20/- each (which will not be returned).

The Directors do not bind themselves to accept the lowest or any Tender.

S. G. S. YOUNG, Secretary.

Offices: The White House, 91, Petty France, Westminster, S.W. 1.
13th March, 1922. T 741

LONDON COUNTY COUNCIL.

Offers are Invited for the PURCHASE and REMOVAL of one Dick, Kerr MOTOR BOOSTER SET, comprising 106 HP. shunt wound motor 600 volts D.C., direct coupled to 72 Kw. 60 volt series wound booster, the speed of the set being 600 r.p.m.

The Booster Set may be inspected by arrangement at the Council's Substation, 20, Brixton Road, S.W., from 20th to 27th March, 1922, both dates inclusive. Applications to inspect the machine should be addressed to the General Manager, L.C.C. Tramways, 23, Belvedere Road, S.E. 1.

Offers for the purchase of the machine must be addressed to the General Manager, L.C.C. Tramways, and delivered not later than Eleven a.m. on Thursday, 30th March, 1922.

The Council does not bind itself to accept the highest or any Offer.

JAMES BIRD, Clerk of the London County Council. T 757

THE GREAT INDIAN PENINSULA RAILWAY COMPANY.

The Directors are prepared to receive

Tenders for the Supply of the following STORES, namely:—

No.		Fee for Specification.
1.	STEEL WORK for Bridges	£1 0 0

Specifications and Forms of Tender may be obtained at this office on payment of the fee for the Specification, which payment will not be returned.

The fee should accompany any application by post. Cheques and Postal Orders should be crossed and made payable to the Great Indian Peninsula Railway Company.

Tenders must be delivered in separate envelopes, sealed and addressed to the undersigned, marked "Tender for Steel Work for Bridges," or as the case may be, not later than Eleven o'clock a.m. on Tuesday, the 28th March, 1922.

The Directors do not bind themselves to accept the lowest or any Tender.

R. H. WALPOLE, Secretary.

Company's Offices, 43, Copthall Avenue, London, E.C. 2.
15th March, 1922. T 732

EAST INDIAN RAILWAY.

The East Indian Railway Company is prepared to receive

Tenders for the Supply and DELIVERY of:—
(1) GALVANIZED CORRUGATED SHEETS.
(2) OPEN AND COVERED GOODS WAGONS
(3) WHEELS AND AXLES
(4) WHEEL LATHES

as per Specifications to be seen at the Company's Offices.

Tenders are to be sent to the undersigned, not later than Eleven o'clock a.m., marked "Tender for Galvanized Sheets," or as the case may be, for No. 1 on Wednesday, the 29th day of March instant, and for Nos 2, 3 and 4 on Wednesday, the 5th day of April proximo.

The Company reserves to itself the right to divide the order, also to decline any Tender without assigning a reason, and does not bind itself to accept the lowest or any Tender.

For each Specification a fee of £1 1s. is charged, which cannot under any circumstances be returned.

By Order, G. B. LILLIE, Secretary.

Nicholas Lane, London, E.C. 4.
15th March, 1922. T 751

APPOINTMENTS OPEN.

CHESHIRE COUNTY COUNCIL. EDUCATION DEPARTMENT.

NORTHWICH VERDIN TECHNICAL SCHOOL AND SCHOOL OF ART.

Wanted, for September next, a FULL-TIME ADDITIONAL LECTURER for Major Engineering Course. An Engineering Graduate with Works and Teaching Experience preferred. Salary in accordance with the Burnham Scale.

Forms of Application and further particulars may be obtained from A. E. THOMAS, Esq., Education Office, Northwich.

C. F. MOTT, M.A., Director of Education. T 721

The Stanton Ironworks Com- PANY, LTD., near Nottingham, hereby announce that they have now FILLED the APPOINTMENT of Works Manager for their Reinforced Concrete Works, and would be glad if all applicants would take this as an official notification. T 706

Electrical Engineer Required to prepare estimates and designs for direct current generators, especially of high speed type. Give details of training, experience and salary.—Address, T 748, Offices of ENGINEERING.

Wanted by Electrical Firm, PRODUCTION ENGINEER. State experience and salary required.—Address, T 758, Offices of ENGINEERING.

Assistant Engineer Re- QUIRED by the GOVERNMENT OF NIGERIA for the Public Works Department for two tours of from 12 to 18 months' service with possible extension. Salary £480 per annum rising by annual increments of £30 to £720 per annum and thence by annual increments of £40 to £920 per annum.

Outfit allowance of £60 paid on first appointment. Free first-class passages and single quarters provided. Liberal leave in England on full salary after each tour.

Candidates, age between 25 and 35, preferably single, must have had good practical experience as Civil Engineers upon Public Works, buildings and road making and preferably should be A.M.I.C.E.

Apply at once in writing, giving age and brief details of experience, to CROWN AGENTS FOR THE COLONIES, 4, Millbank, London, S.W. 1, quoting M/Nigeria 11316. T 760

BRITISH NORTH BORNEO.

Required Immediately in the PUBLIC WORKS DEPARTMENT OF NORTH BORNEO, TWO ENGINEERS.

Candidates should be single and under 30 years of age; active, of good physique, with thorough knowledge of instrument work and well trained in ordinary engineering knowledge; must have been trained in a recognised Engineering College and should have passed A.M.I.C.E. Exam., or held exempting degree; should have had good practical experience on Public Works. Preference for one appointment will be given to candidate with Waterworks experience.

Salary £490, rising annually by £21 with house or house allowance, and duty allowance of £56. Five years' agreement, with first-class free passage out and home on completion of agreement. Appointment subject to medical examination.

Apply (in writing) not later than 3rd April, with full record of career in chronological order, giving age and details of general and technical education, training and subsequent experience, testimonials (Copies only), service certificates, etc., to Messrs. RENDEL, PALMER & TRITTON, 12-14, Dartmouth Street, S.W. 1. T 731

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Draughtsman Wanted for Glasgow, with knowledge of Drop Valve Engines and Corliss Gear. State age, experience and salary required.—Address, T 703, Offices of ENGINEERING.

Wanted, Salesman with connection capable of handling Steam Specialities, Feed Pumps, etc. Salary and previous experience.—Address, T 680, Offices of ENGINEERING.

Articled Pupil.—Civil Engi- NEER, M.Inst.C.E., Cambridge Graduate, HAS VACANCY in his Office, Waterworks, Sewerage, Bridges, Buildings, Roads, etc.—For further particulars address, T 654, Offices of ENGINEERING.

Wanted, for Constructional Engineering and Boiler Works, FOREMAN over Smiths and Welders. Experience in Hydraulic Presswork, Oxy-acetylene and Electric Welding Process essential.—Write, giving qualifications, age, salary, and when at liberty, to THE SECRETARY, CLAYTON, SON & Co., Ltd., Moor End Works, Hunslet, Leeds. T 744

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Engineer (28), Technical education, practical training. Experience as Chief Draughtsman and Works Manager, DESIRES POST as Technical Assistant or training in special brand of Engineering for Commercial purposes.—Address, T 644, Offices of ENGINEERING.

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Engineer 35, A.M.I.M.E., M.I.A.E. many years experience Works and Business Management and with complete commercial experience including Sales Organisation, Experienced Designer, and with extensive knowledge of Works Accountancy, shortly relinquishing Managing Directorship, seeks Responsible Managerial Appointment. Would entertain home, continental, or foreign representation.—T 445, Offices of ENGINEERING.

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STATICALLY INDETERMINATE AND NON-ARTICULATED STRUCTURES.

By Professor F. C. LEA, D.Sc., M.Inst.C.E., M.Inst.Mech.E., M.I.M., A.R.C.S., Wh.Sc.

THE determination of the forces and thus the stresses* in the members of articulated structures without redundant members is not as a rule difficult; the ordinary principles of statics are sufficient. Similarly the stresses in beams, in those cases where the external bending moments at any sections of the beams can be determined by the ordinary principles of statics, are on the usual assumptions easily obtained. Many modern steel structures, and also reinforced concrete structures, consist of non-articulated elements, and as a matter of fact depend for their stability upon the rigidity of the joints connecting the elements. Such structures are said to be statically indeterminate, and principles other than those of statics have to be applied to determine the stresses in the elements of the structure.

Well-known cases are those of the continuous beam, the two-pin and pinless arches, which can generally be solved by the application of the elastic theory in the manner discussed in the text books. A number of methods of dealing with statically indeterminate structures have been developed, with which designers should be familiar, and it is the object of this paper to show how a number of important practical problems can be solved by the application of the two theorems known as Castigliano's theorems, and the Principle of Least Work, which can be said to be a special case of Castigliano's theorems.

CASTIGLIANO'S THEOREM AND THE PRINCIPLE OF LEAST WORK.

(1)† If any elastic structure is subject to a system of external forces, the deflection of the structure at any point where any load P is applied, in the direction of that load, is equal to the differential of the total internal work done, expressed as a function of the external loads, with respect to the given load.

(2) If any elastic structure is subject to any system of forces or couples, the differential of the total internal work, expressed as a function of the loads and couples, with respect to any couple M acting on the structure, is equal to the rotation of the axis of this couple.

(3) The principle of least work can be proved by Castigliano's theorem, or it may be considered as an application of the principle of the conservation of energy. It simply states that when a statically indeterminate structure is loaded in any manner, the structure is so stressed that the internal work is a minimum, or in other words, the differential coefficient of the total internal work with respect to the force in any redundant member, or with respect to any statically indeterminate force that does not move through any distance or couple that does not rotate through any angle is equal to zero.

Let any structure, Fig. 1, consisting of tension and compression members only be loaded with any system of loads which produce in the members forces F_1, F_2, F_3, &c. Let it be assumed that there are one or more redundant members in which the forces are T, T_1, &c. Then if W, W_1, W_2, &c., are the loads on the structure, and each redundant member is replaced by two forces each equal to T applied to the structure in the usual way, the force F in any member of the structure can in all cases be expressed as —

$$F = k W + k_1 W_1 + k_2 W_2 + \ldots + k_t T + \ldots$$

where k_1, k_2, &c., are constants depending upon the configuration of the structure.

Then

$$\frac{dF}{dT} = k_t$$

The total work done on the structure is:

$$U = \Sigma \tfrac{1}{2} \frac{F^2 l}{A E}$$

$$\frac{dU}{dT_1} = \Sigma F \frac{dF}{dT} \cdot \frac{l}{AE}$$

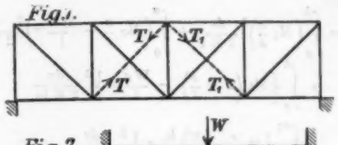
$$= \Sigma F k_t \cdot \frac{l}{AE} = 0$$

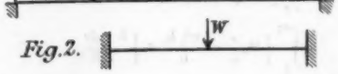
or if F_0 is the force in any member due to the external loads,

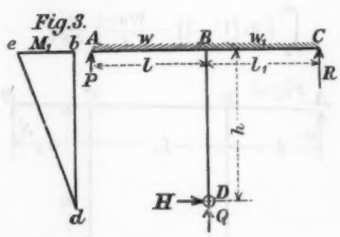
$$\frac{dU}{dT} = \Sigma (F_0 + k_t T + k_{t1} T_1 + \&c.) k_t \frac{l}{AE}$$

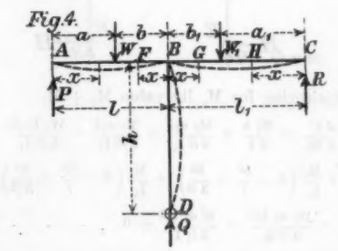
It will be noticed that k_t is the force produced in the member by unit load replacing T.

Similarly if the structure has all its members subject to flexure only and T, T_1, &c., be any loads that are statically indeterminate, while W, W_1, W_2, &c., are known applied loads, the bending moment









at any section can be expressed as a function of some variable x.

$$M = W f(x) + W_1 f_1(x) + \ldots + T f_t(x) + \ldots$$

and

$$\frac{dM}{dT} = f_t(x)$$

The total work is

$$U = \Sigma \frac{M^2 dx}{2EI}$$

and

$$\frac{dU}{dT} = \Sigma M \cdot \frac{dM}{dT} \cdot \frac{dx}{EI} = 0$$

$$= \Sigma \frac{M \cdot f_t(x)\, dx}{EI} = 0$$

It will be noticed that (fx) is the bending moment produced at any section by unit load at the place where T is applied.

If loads W, W_1, &c., are applied to the structure and there are produced bending moments M_0, M_1, &c., which cannot be statically determined, the bending moment at any section can generally be expressed as:

$$M = W f(x) + W_1 f_1(x) + \ldots + M_0 f_m(x) + \ldots$$

and

$$\frac{dM}{dM_0} = f_m(x)$$

Then

$$U = \Sigma \frac{M^2 dx}{2EI}$$

and

$$\frac{dU}{dM_0} = \Sigma M \frac{dM}{dM_0} \cdot \frac{dx}{EI} = 0$$

$$= \Sigma M f_m(x) \frac{dx}{EI} = 0$$

It will be noticed that $f_m(x)$ is the moment produced by a unit moment acting where M_0 acts. One or two elementary examples will illustrate the method.

(1) A beam fixed at both ends with a load W at the centre of the span.

Here the unknown couples are the two equal couples at the supports. Let M_0 be the bending moment at either end of the beam, Fig. 2.

Then the bending moment at any section distant x from the support is

$$M = M_0 - \frac{W}{2} x$$

$$U = 2 \int_0^{\frac{l}{2}} \left(M_0 - \frac{W}{2} x\right)^2 \frac{dx}{2EI}$$

$$\frac{dU}{dM_0} = 2 \int_0^{\frac{l}{2}} \left(M_0 - \frac{W}{2} x\right) \frac{dx}{EI} = 0$$

$$= \left(M_0 \frac{l}{2} - \frac{W}{2} \frac{l^2}{8}\right) = 0 \text{ or } M_0 = \frac{Wl}{8}$$

which is a well-known result.

As an important, and not difficult problem consider the case of a beam rigidly supported at its two ends, and rigidly fixed to a central long column. Such a construction is frequently found in reinforced concrete. Suppose the central column pin jointed at its lower end. If then the two spans are loaded in any manner the column will be subjected to bending moments which will cause flexure of the column, as indicated in Figs. 3 and 4.

At the pin D there will, therefore, be a horizontal reaction H and a vertical reaction Q; at A and C there will be vertical reactions P and R and a horizontal reaction to balance H at one or both A and C.

It is assumed that the column is rigidly fixed to the beam at B, and that all the work on the column is done by bending.

The beam A B C is thus fixed to a central column B D of length h. The column B D is subject to flexure, and the work done due to direct compression is neglected as compared with the work done by bending. Let M_0 be the bending moment to the left of B; M_2 the B M to the right of B and M_1, the bending moment at the top of the column below B. Then:

$$M_2 = M_0 + M_1$$

The bending moment diagram for the post is the triangle $e\,b\,d$, and the bending moment at any distance x from D is $\frac{M_1 x}{h}$

Let A B = l, B C = l_1, B D = h, and let A B and B C be covered with uniformly distributed loads w and w_1 tons per foot respectively.

I_0 = moment of inertia of A B.
I_1 = " " B C.
I = " " B D.

Then the work done by flexure is

$$U = \int_0^h \left(\frac{M_1 x}{h}\right)^2 \frac{dx}{2EI} + \int_0^l \left(M_0 \frac{x}{l} - \frac{w l}{2} x + \frac{w x^2}{2}\right)^2 \frac{dx}{2EI_0}$$

$$+ \int_0^{l_1} \left(\frac{M_0 x}{l} + \frac{M_1 x}{l_1} - \frac{w_1 l_1 x}{2} + \frac{w_1 x^2}{2}\right)^2 \frac{dx}{2EI_1} \quad (1)$$

From which

$$3 \frac{dU}{dM_1} = \frac{1}{I} M_1 + \frac{1}{I_1} \left(M_0 + M_1 - \frac{w_1 l_1^2}{8}\right) = 0 \quad (2)$$

$$3 \frac{dU}{dM_0} = \frac{1}{I_0} \left(M_0 - \frac{w l^2}{8}\right) + \frac{1}{I_1} \left(M_0 + M_1 - \frac{w_1 l_1^2}{8}\right) = 0 \quad (3)$$

Now let

$$\frac{I_1}{l_1} \times \frac{h}{I} = r \quad \text{and} \quad \frac{I_0}{l} \times \frac{l_1}{I_1} = p$$

Then from (2):

$$M_1 + \frac{1}{r} \left(M_0 + M_1 - \frac{w_1 l_1^2}{8}\right) = 0 \quad (4)$$

and from (3):

$$\frac{1}{p} \left(M_0 - \frac{w l^2}{8}\right) + M_0 + M_1 - \frac{w_1 l_1^2}{8} = 0 \quad (5)$$

Multiply (4) by r:

$$r M_1 + M_0 + M_1 - \frac{w_1 l_1^2}{8} = 0. \quad (6)$$

* Many writers use the term stress and force in a member indiscriminately. The writer prefers to reserve stress for the force per unit area.

† See paper by the author in the Library Institution of Civil Engineers. "The use of the Influence Diagram for determining the deflection of structures."

Subtracting (6) from (5):

$$\frac{1}{p}\left(M_0 - \frac{w l^2}{8}\right) - r M_1 = 0$$

$$\therefore M_0 = r p M_1 + \frac{w l^2}{8} \quad . \quad . \quad . \quad (7)$$

Substituting in (6):

$$r M_1 + r p M_1 + M_1 + \frac{w l^2 - w_1 l_1^2}{8} = 0 \quad . \quad (8)$$

or

$$M_1 = \frac{w_1 l_1^2 - w l^2}{8\left\{1 + r(p+1)\right\}} \quad . \quad . \quad (9)$$

Now let the horizontal reaction at the pin D be H, then $M_1 = Hh$, and

$$H = \frac{w_1 l_1^2 - w l^2}{8h\left\{1 + r(p+1)\right\}} \quad . \quad . \quad (10)$$

From (7):

$$M_0 = \frac{w l^2}{8} + \frac{r p (w_1 l_1^2 - w l^2)}{8\left\{1 + r(p+1)\right\}}$$

$$= \frac{w l^2}{8} + \frac{w_1 l_1^2 - w l^2}{8}\left\{\frac{r p}{1 + r(p+1)}\right\} \quad (11)$$

Now let P be the reaction at A.

Then

$$M_0 = \frac{w l^2}{2} - P l$$

or

$$P l = \frac{3 w l^2}{8} - \frac{r p (w_1 l_1^2 - w l^2)}{8\left\{1 + r(p+1)\right\}} \quad (12)$$

from which

$$P = \frac{3}{8} w l - \left(\frac{r p}{1 + r + r p}\right)\frac{w_1 l_1^2 - w l^2}{8 l}$$

When the moment of inertia is constant for the beam and the column and the length $l = l_1$, $r = \frac{h}{l}$ and $p = 1$.

Then

$$P = \frac{l(7wh + 3wl - w_1 h)}{8(l + 2h)}$$

and

$$H = \frac{l^3(w_1 - w)}{8h(l + 2h)}$$

When $w = w_1$ and h is zero

$$P = \frac{3 wl}{8}$$

Now:

$$M_2 = M_1 + M_0$$

$$= \frac{w l^2}{8} + \frac{r p(w_1 l_1^2 - w l^2)}{8(1 + r + r p)} + \frac{w_1 l_1^2 - w l^2}{8(1 + r + r p)} \quad (13)$$

$$= \frac{r w l^2 + (1 + r p) w_1 l_1^2}{8(1 + r + r p)} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

From (11)

$$M_0 = \frac{w l^2(1 + r) + r p w_1 l_1^2}{8(1 + r + r p)} \quad . \quad . \quad (15)$$

Suppose

$$l_0 = l_1; \quad p = 1$$

Then

$$M_0 = \frac{w l^2(1 + r) + r(w_1 l_1^2)}{8(1 + 2r)} \quad . \quad . \quad (16)$$

and

$$M_2 = \frac{w_1 l_1^2(1 + r) + r w l^2}{8(1 + 2r)} \quad . \quad . \quad (17)$$

If $\frac{w l^2}{8} = N$ and $\frac{w_1 l_1^2}{8} = N_1$ the equations can be simplified. It is interesting to note that if the beam A B were supposed to be rigidly fixed at the ends, the bending moment at A and also B would be $\frac{w l^2}{12}$. Then

$$N = \frac{w l^2}{12} + \tfrac{1}{2}\frac{w l^2}{12}.$$

Similarly

$$N_1 = \frac{w_1 l_1^2}{12} + \tfrac{1}{2}\frac{w_1 l_1^2}{12}$$

The reactions R and Q, at C and D respectively, can now be found.

$$M_2 = \frac{w_1 l_1^2}{2} - Q l_1$$

$$\therefore Q l_1 = \frac{w_1 l_1^2}{2} - \frac{r w l^2 + (1 + r p) w_1 l_1^2}{8(1 + r + r p)}$$

or substituting from (13):

$$Q l_1 = \frac{3 w_1 l_1^2}{8} - \frac{r p (w_1 l_1^2 - w l^2) - w_1 l_1^2 + w l^2}{8(1 + r + r p)}$$

$$= \frac{3 w_1 l_1^2 + 3 r w_1 l_1^2 + 3 r p w_1 l_1^2 - r p w l^2 - r p w_1 l_1^2 + r p w l^2 - w_1 l_1^2 + w l^2}{8(1 + r + r p)}$$

$$Q = \frac{w_1 l_1^2(2 + 3r + 2rp) + w l^2(1 + r p)}{8 l_1(1 + r + r p)} \quad *(18)$$

From (12):

$$P = \frac{w l^2(3 + 4 r p + r p) - w_1 l_1^2 r p)}{8 l(1 + r + r p)} \quad *(19)$$

and

$$R = w l + w_1 l_1 - (Q + P)$$

* As a check of these equations take moments about C then

$$P(l + l_1) - H h + R l_1 - w l\left(\frac{l}{2} + l_1\right) - \frac{w_1 l_1^2}{2} = 0$$

In (18), suppose $l = l_1$, and $p = 1$. Then

$$Q = \frac{l^2 w_1(2 + 3r + 2r) + w l^2(1 + r)}{8 l(1 + 2r)}$$

If $r = 1$, $w = w_1$, and $l = l_1$, $Q = \frac{3}{8} w l^2$. This is the same result as when the strut is short; the moment on the column is zero and H is zero.

Now suppose the load on A B is a concentrated load W at distance a from A, and the load on B C a concentrated load W_1 (Fig. 4). The moment at F due to the couple M_0 in the length a is $\frac{M_0 x}{l}$ and the moment at F in the length b is $M_0\left(1 - \frac{x}{l}\right)$; the moment at E due to W is $\frac{W b x}{l}$ and at F is $\frac{W a x}{l}$. Similarly the moments at G in B C can be written down.

Then

$$U = \int_0^h \left(M_1 \frac{x}{h}\right)^2 \frac{dx}{2 E I} + \int_0^a \left(M_0 \frac{x}{l} - \frac{W b}{l} x\right)^2 \frac{dx}{2 E I_0}$$

$$+ \int_0^b \left\{M_0\left(1 - \frac{x}{l}\right) - \frac{W a}{l} x\right\}^2 \frac{dx}{2 E I_0}$$

$$+ \int_0^{a_1} \left\{M_2 \frac{x}{l_1} - \frac{W_1 b_1}{l_1} x\right\}^2 \frac{dx}{2 E I_1}$$

$$+ \int_0^{b_1} \left\{M_2\left(1 - \frac{x}{l_1}\right) - \frac{W a x}{l}\right\}^2 \frac{dx}{2 E I_1} \quad . \quad (1)$$

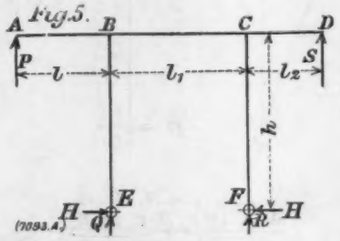


Fig. 5.

Substituting for M_2 its value $M_0 + M_1$

$$\frac{d U}{d M_1} = \frac{M_1 h}{3 I} + \frac{M_0 a_1^3}{3 l^2 I_1} + \frac{M_1 a_1^3}{3 l^2 I_1} - \frac{W_1 b_1 a^3}{3 l^2 I_1}$$

$$+ \frac{M_0}{I_1}\left(b - \frac{b^2}{l} + \frac{b^3}{3 l^2}\right) + \frac{M_1}{I_1}\left(b - \frac{b^2}{l} + \frac{b^2}{3 l^2}\right)$$

$$+ \frac{W_1 a_1 b_1^3}{3 l^2 I_1} - \frac{W a_1 b_1^2}{2 l_1 I_1} = 0 \quad . \quad . \quad . \quad (2)$$

or

$$\frac{M_1 h}{3 I} + \frac{M_0 l}{3 I_0} - \left\{\frac{W(b a^3 - a b^3)}{3 l^2 I_0} + \frac{W}{2}\frac{a b^2 l}{I_0 l^2}\right\} + \frac{M_0 l_1}{3 I_1} + \frac{M_1 l_1}{3 I_1}$$

$$- \left\{\frac{W_1}{3 l_1^2 I_1}(b_1 a_1^3 - a_1 b_1^3) + \frac{W}{2}\frac{a_1 b_1^2}{l_1 I_1}\right\} = 0 \quad (3)$$

i.e.,

$$\frac{M_1 h}{I} + \frac{M_0 l_1}{I_1} + \frac{M_1 l_1}{I_1} - \left(\frac{W_1}{l_1 I_1} a^2 b + \frac{W_1 a b^2}{2 l_1 I_1}\right) = 0 \quad (4)$$

Similarly

$$\frac{d U}{d M_0} = \frac{M_0 l}{I_0} - \left(\frac{W a^2 b}{l I_0} + \frac{W a b^2}{2 l I_0}\right) + \frac{(M_0 + M_1) l_1}{I_1}$$

$$- \left(\frac{W_1 a_1^2 b_1}{l_1 I} + \frac{W_1 a_1 b_1^2}{2 l_1 I_1}\right) \quad . \quad . \quad (5)$$

Let

$$\frac{W a^2 b}{l^2} + \frac{W a b^2}{2 l^2} = N^* \text{ and } \frac{W_1 a_1^2 b_1}{l_1^2} + \frac{W_1 a_1 b_1^2}{2 l_1^2} = N_1 \quad (6)$$

Now let

$$\frac{I_1}{l_1} \times \frac{h}{I} = r$$

and

$$\frac{I_0}{l} \times \frac{l_1}{I_1} = p$$

Then

$$M_1 = \frac{N_1 - N}{1 + r(p+1)} \quad . \quad . \quad . \quad (7)$$

$$M_0 = N + \frac{r p (N_1 - N)}{1 + r(p+1)} \quad . \quad . \quad (8)$$

$$M^2 = \frac{r N + (1 + r p) N_1}{1 + r(p+1)} \quad . \quad . \quad . \quad (9)$$

Similarly if there are any number of loads W, W^1, W^{11}, &c., on the span A B and on B C, loads W_1, W_1^1, W^{11}, &c., the value of

$$N = \Sigma\left(\frac{W a^2 b}{l^2} + \frac{W a b^2}{2 l^2}\right)$$

of

$$N_1 = \Sigma\left(\frac{W_1 a_1^2 b_1}{l_1^2} + \frac{W_1 a_1 b_1^2}{2 l_1^2}\right)$$

and M_1, M_0 and M_2 are given by the equations (7), (8) and (9).

CONTINUOUS BEAM A D, FIG. 5, RIGIDLY CONNECTED TO TWO COLUMNS AT B AND C, WHICH ARE PIN-JOINTED AT THE LOWER ENDS.

First assume uniformly-distributed loads w, w_1 and w_2 per foot run, on spans l, l_1 and l_2 respectively.

The moment to the left of B is

$$M_B = \frac{w l^2}{2} - P l + H h$$

and the right of C is

$$M_C = \frac{w_2 l_2^2}{2} - S l_2 + H h$$

The bending moment at any point in B C at x from B is

$$M = M_B - (M_B - M_C)\frac{x}{l} - \frac{w_1 l_1^2}{2} + \frac{w_1 x^2}{2}$$

The total work done is

$$U = \int_0^l \left(\frac{w x^2}{2} - P x\right)^2 \frac{d x}{2 E I} + \int_0^{l_2} \left(\frac{w_2 x^2}{2} - S x\right)^2 \frac{dx}{2 E I_2}$$

$$+ \int_0^{l_1} \left\{\left(\frac{w l^2}{2} - P l + H h\right)\left(1 - \frac{x}{l_1}\right) + \left(\frac{w_2 l_2^2}{2} - S l_2 + H h\right)\frac{x}{l_1}\right.$$

$$\left. - \frac{w_1 l_1 x}{2} + \frac{w_1 x^2}{2}\right\}^2 \frac{d x}{2 E I_1} + 2\int_0^h (H x)^2 \frac{d x}{2 E I_0} \quad (1)$$

Then

$$\frac{d U}{d P} = 0 = \frac{P l^3}{3 I} + \frac{P l^2 l_1}{3 I_1} + \frac{S l_2 l_1}{6 I_1} - \frac{H h l l_1}{2 I_1}$$

$$- \frac{w l^4}{8 I} - \frac{w l^3 l_1}{6 I_1} + \frac{w_1 l l_1^3}{24 I_1} - \frac{w_2 l l_1 l_2^2}{12 I_1} \quad . \quad (2)$$

$$\frac{d U}{d H} = -\frac{P l l_1}{2 I_1} - \frac{S l_2 l_1}{2 I_1} + \frac{H h l_1}{I_1} + \frac{2}{3}\frac{H h^2}{I_0}$$

$$+ \frac{w l^2 l_1}{4 I_1} - \frac{w_1 l_1^3}{12 I_1} + \frac{w_2 l_2^2 l_1}{4 I_1} = 0 \quad . \quad (3)$$

$$\frac{d U}{d S} = \frac{P l l_1 l_2}{6 I_1} + \frac{S l_1 l_2^2}{3 I_1} + \frac{S l_2^3}{3 I_2} - \frac{H h l_1 l_2}{2 I_1} - \frac{w l^2 l_1 l_2}{12 I_1}$$

$$+ \frac{w_1 l_2 l_1^3}{24 I_1} - \frac{w_2 l_2^4}{8 I_2} - \frac{w_2 l_2^3 l_1}{6 I_1} = 0 \quad . \quad (4)$$

From equations (2), (3) and (4) P, H and S can be found.

If there are concentrated loads on the beam, these equations are slightly altered, but the student should have no difficulty in substituting the bending moments for concentrated loads exactly as in the previous case. When the moment of inertia of the beam is constant and equal to that of the columns, $w = w_2$ and $l = l_2$

$$P = S = \frac{12 H h l_1 + 3 w l^2(2 l_1 + l) - w_1 l_1^3}{4 l(2 l + 3 l_1)}$$

and

$$H = \frac{l l_1(2 w_1 l_1^2 + 3 w l^2)}{h H(2 h l + 3 h l_1 + 3 l l_1)}$$

When $l = l_1 = l_2$

$$P = S = \frac{3 H h}{5 l} + \frac{l(9 w - w_1)}{20}$$

$$H = \frac{l^3(2 w_1 + 3 w)}{8 h(5 h + 3 l}$$

and

$$Q = R = \frac{11 l(w + w_1)}{20} - \frac{3}{5}\frac{H h}{l}$$

When $w = w_1$ and the supports are firm

$$P = S = \frac{2 w l}{5}$$

and

$$Q = R = \frac{11}{10} w l$$

Instead of working with P, H and S as unknowns, the couples M_{BA}, M_{BE} and M_{CD} can be taken as unknowns, where M_{BA} represents the

* If the beam A B is supposed fixed at both ends the bending moment at A = $\frac{W a^2 b}{l^2}$ and the bending moment at B = $\frac{W a b^2}{l^2}$. *i.e.*, $N = M_A + \frac{1}{2} M_B$ where M_A and M_B would be the end bending moments if the beam were fixed at its ends.

THE THORNYCROFT CONTINU

CONSTRUCTED BY MESSRS. JOHN I. THORNYCR[OFT] AN[D]

(For Descriptio[n], see Pa[ge]

ARRANGEMENT OF SUGAR MACHINERY IN MILL.

Fig. 1. GROUND FLOOR PLAN.

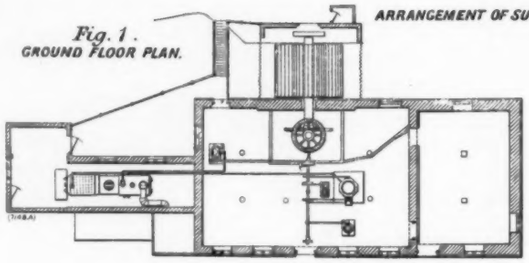


Fig. 2. CROSS SECTION.

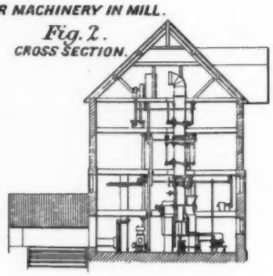


Fig. 3.

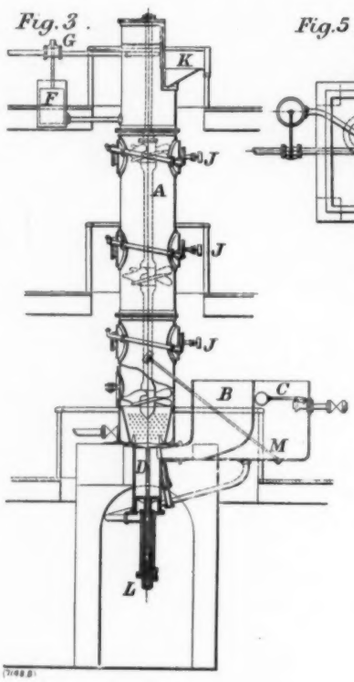


Fig. 5.

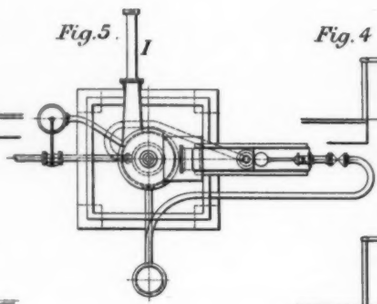


Fig. 4.

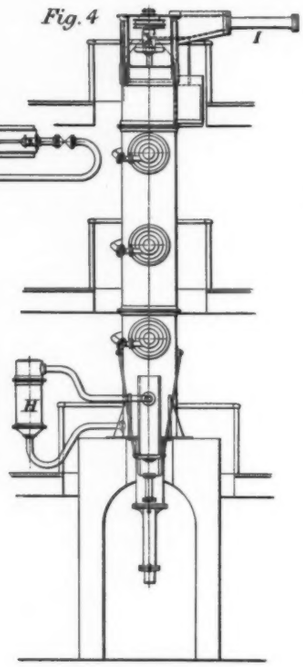


Fig. 6.

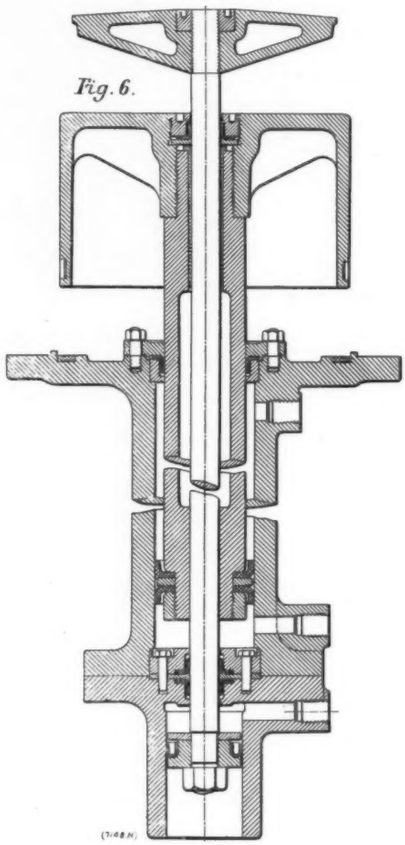


Fig. 7.

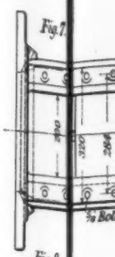


Fig. 8.

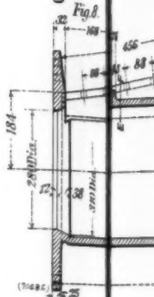


Fig. 13.

Fig. 14.

Fig. 22. SECTION A.B.

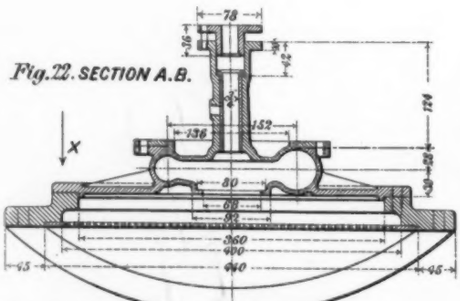


Fig. 24.

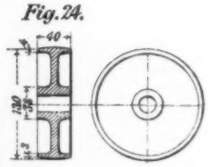


Fig. 25.

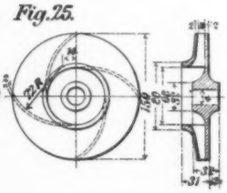


Fig. 23. VIEW LOOKING WITH ARROW X.

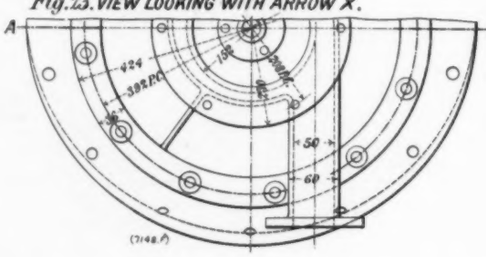


Fig. 26. SEC. ON A-B.

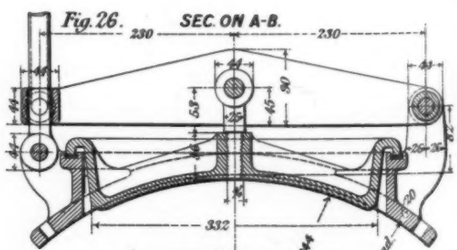
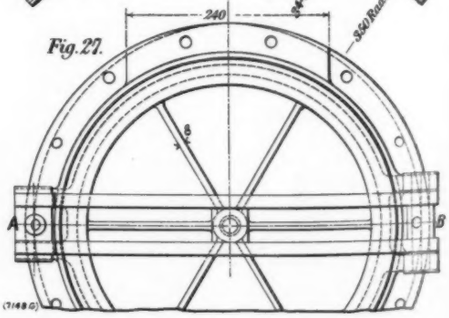


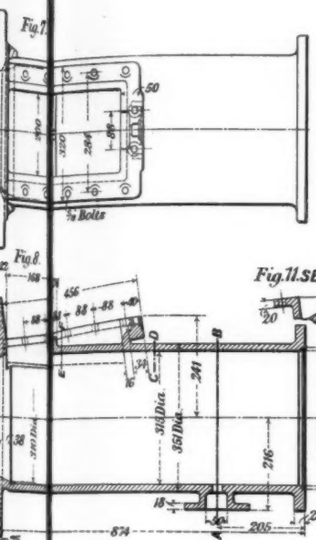
Fig. 27.

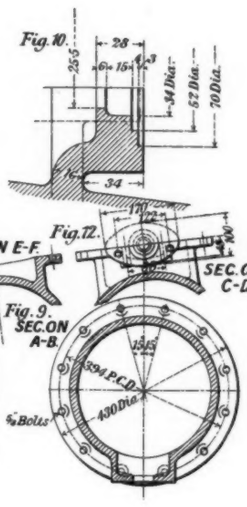


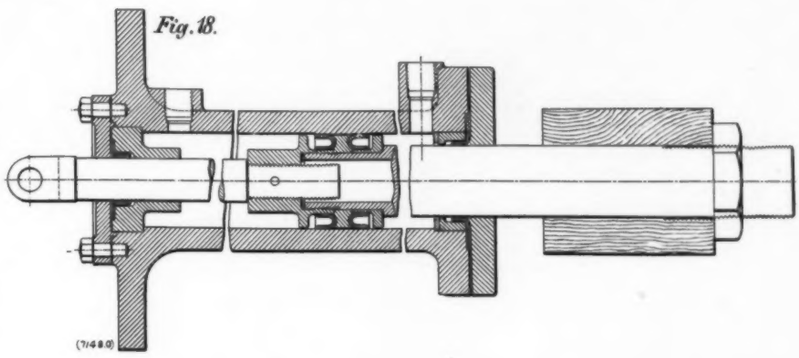
TINUOUS SUGAR BEET DIFFUSER.

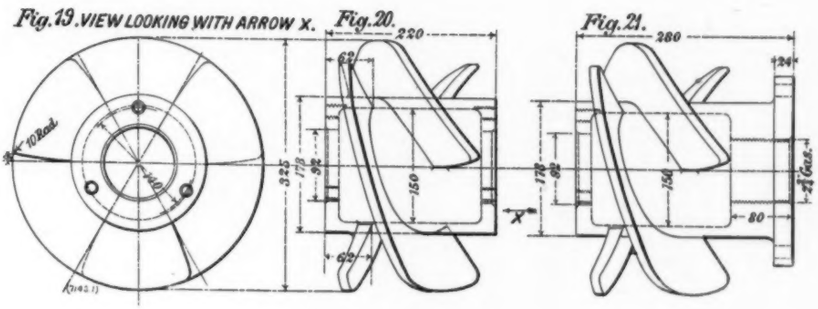
ORNYCROFT AND CO., LIMITED, ENGINEERS, BASINGSTOKE.

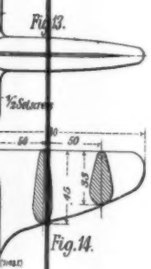
(Description see Page 315.)

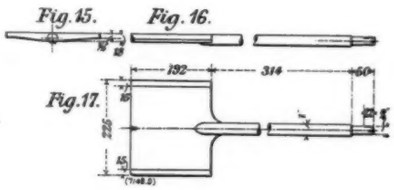


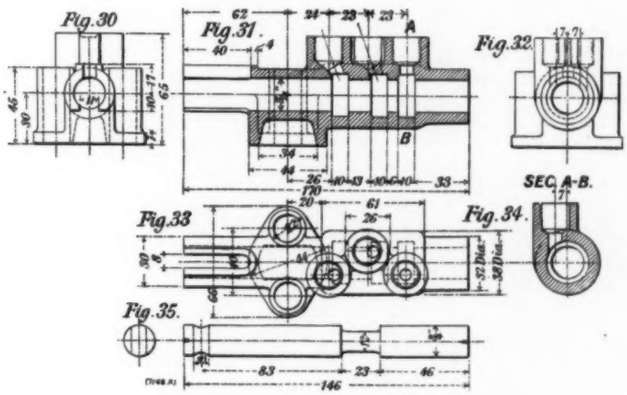


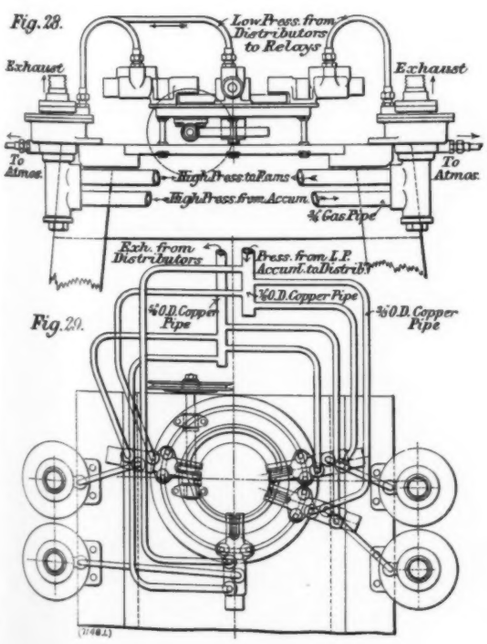


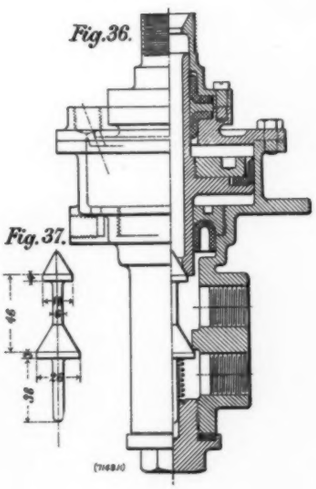


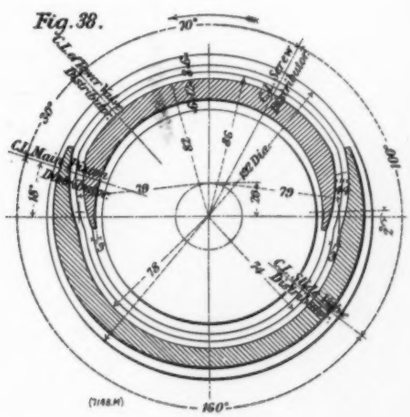












couple to the left of B $M_{B\,E}$, the couple below B, and so on. Let

$$\frac{I_1}{i_1} \times \frac{l}{I} = r$$

$$\frac{I_1}{i_1} \times \frac{l_2}{I_2} = p$$

$$\frac{I_1}{i_1} \times \frac{h}{I_0} = q$$

$$\frac{w\,l^2}{8} = M$$

$$\frac{w_1\,l_1^2}{8} = N$$

$$\frac{w_2\,l_2^2}{8} = V$$

and

$$2q(4rp + 4r + 4p + 3) + 3(4rp + r + p) = X.$$

Then:

$$M_{B\,A} = \frac{-M}{X} 4(p+1)(2q+3) - 9 + \frac{N}{X} 4(2p+1)\left(q + \frac{V}{X} p(3 - 4q)\right) \quad . \quad . \quad . \quad (5)$$

$$M_{B\,E} = \frac{-M}{X} 3r(2p+1) + \frac{N}{X} 2\{(r+1)(4p+1) - (3p+1)\} - \frac{V}{X} 3p(2r+1) \quad . \quad (6)$$

$$M_{B\,C} = \frac{M}{X} 2r\left\{2(p+1)(2q+3) - 3(p+2)\right\} + \frac{N}{X} 2\left\{(2p+1)(2q-1) + (r+1)(4p+1) - p\right\} - \frac{V}{X} 2p(2q+3r) \quad . \quad (7)$$

$$M_{C\,D} = \frac{M}{X} r(3 - 4q) + \frac{N}{X} 4(2r+1)q + \frac{V}{Z} p\left\{(r+1)(2q+3)4 - 9\right\} \quad . \quad (8)$$

$$M_{C\,F} = \frac{-M}{X} 3r(2p+1) + \frac{N}{X} 2\{(r+1)(4p+1) - (3p+1)\} - \frac{V}{X} 3p(2r+1) \quad . \quad (9)$$

$$M_{C\,B} = \frac{-M}{X} 2r(2q+3p) + \frac{N}{X} 2\left\{r(4p+1) + 2(2r+1)(q) + p\right\} + \frac{V}{X} 2p\{(2r+1)(2q+3) - 3(2+2)\} \quad . \quad (10)$$

As a check, $M_{B\,E} = H \,.\, h$. When $l = l_1 = l_2$ and I is constant, r, p and q are unity, and

$$H = \frac{l^2}{8h}\left(\frac{2w_1 + 3w}{5h + 3l}\right).$$

(To be continued.)

THE THORNYCROFT CONTINUOUS SUGAR BEET DIFFUSER.

IN the manufacture of sugar from beet the roots are cut into slices and are steeped in hot water in an apparatus known as a diffuser. The sugar dissolves from the beet and a solution, or "sirop," is obtained. This "sirop" is then treated with lime to precipitate non-sugars, is filtered, bleached and evaporated in vacuum pans. With the details of these latter processes we are not concerned in this article, the purpose of which is to describe a form of continuous diffuser which has been worked out by Sir John I. Thornycroft. The diffusion process is a very important step in the manufacture of beet sugar, and a description of the Thornycroft apparatus may well be prefaced by a short account of the process as commonly carried out. In no other way could the special features of the Thornycroft diffuser be made clear to those who are not intimate with beet sugar manufacture.

As before explained, the beet-roots cut into slices are steeped in hot water. The sugar in the beet is contained in minute plant cells and although, of course, a proportion of these are cut open in the slicing, the majority are unbroken. The sugar passes from these to the water by a process of dialysis, so that some time is necessary for the complete removal of the sugar. In the early days of the manufacture of beet sugar the roots were crushed, or rasped, so that the cells were destroyed. This cut down the time required for diffusion, but had the disadvantage that the whole of the colloidal non-sugars present in the cells passed into the "sirop." In the diffusion process as now practiced, and as described above, the non-sugars pass out of the cells more slowly than the sugar so that a product is obtained, which although in a dilute state, is purer in sugar than is the original juice in the beet.

If a charge of sliced beet is steeped in sufficient water to cover it sugar will diffuse out of the cells only until the strength of solution is equal inside the cells and out. If the beet is then discarded, it will carry away a proportion of the sugar with it and the richer the "sirop" which has been formed the larger the amount of sugar lost. If sufficient water is added to make this final loss negligible, it will be clear that an extremely dilute "sirop" will be obtained requiring a large amount of evaporation. To get over this difficulty diffusion is carried out in a number of stages. The apparatus used consists of a series of cylindrical tanks which are arranged either in a circle or in parallel lines. These are loaded with sliced beet, and diffusion takes place in them. Ten or 12 of these diffusers go to make up a battery.

In normal operation each diffuser is charged with fresh beet in turn and the "sirop" passes through the range from one diffuser to another, valve connections being provided to allow this to be done. A diffuser which has just been charged with fresh beet always becomes the last of the range. It is fed with "sirop" from the one previously charged, and this in turn is fed from the one before and so on. The result of the arrangement is that each diffuser is at each change fed with "sirop" of a lower density than that which it displaces. Each diffuser in a 12-diffuser battery is subjected to 12 different changes of "sirop" of gradually decreasing density, the final charge being with fresh water, which leaves the beet practically free from sugar. It will be understood that each diffuser alters its relative position in the cycle as each fresh charge of beet is fed to the battery. What was the first diffuser becomes the second, the second becomes the third, and so on. After 12 chargings in a 12-diffuser battery what was once the first diffuser becomes the twelfth and the spent beet is then removed from it, a new charge inserted, the diffuser then again taking the first position in the cycle. The diffusers do not themselves move, but pipe and valve connections have to be made to each so that each may be connected to the next, and finished "sirop" may be drawn from each or fresh water supplied to it. The process is a continuous one and is carried on night and day during the season when the beet crop comes in from the fields. This season lasts about 100 days.

It will be clear from this brief description that a diffusion battery is a bulky piece of apparatus, occupying much floor space and, forming an expensive item in a beet sugar factory. Considerable attention is also required in connection with the passing of the "sirop" around the battery of tanks, while the arrangement presents a very large surface for loss of heat by radiation, the process being carried out at a temperature not greatly below the boiling-point of water. These considerations have resulted in attempts being made at various times to construct continuous diffusers. In the past these, as far as we know, have not been successful, and great interest is as a consequence likely to be taken in the Thornycroft diffuser which has given very promising results on test and is now being put into commercial operation. Sir John I. Thornycroft's attention was directed to this subject towards the end of the war, when sugar was scarce in this country, and as a result of his studies he designed a continuous diffuser and constructed a model plant capable of dealing with 30 kg. of beet an hour. Tests of this were so satisfactory that a larger model capable of diffusing 550 kg. of beet an hour was constructed and erected in an old water mill at Old Basing, near Basingstoke, for experimental running and tests. The diffuser erected in the mill is shown in Figs. 1 and 2, on Plate XVI, while separate views of the machine itself to a larger scale are given in Figs. 3 to 5.

It will be gathered from these illustrations that the diffuser consists of a single chamber in the form of a vertical cylindrical tank. The whole of the diffusion process takes place in this single chamber, the sliced beet entering at the bottom and being removed fully exhausted from the top. The various parts of the plant are illustrated in considerable detail in Figs. 6 to 38, on Plate XVI, but before dealing with these reference may be made to Figs. 40 to 41, on page 328, which give general views of the diffuser as erected in Messrs. Thornycroft's Basingstoke works. These two illustrations give a good idea of the general appearance of the plant and of its size. It should be understood however, that when the plant is finally erected in a sugar factory somewhat more extensive facilities will be provided for obtaining access to the top of the diffuser for the purpose of removing the spent beet. This would be arranged either by providing a larger top platform or by fixing the plant so that it projected through one or more of the floors of the building in which it was fixed, as in the installation in the mill shown in Fig. 2 and in Figs. 3 and 4. Although this plant is quite a large piece of apparatus, as will be clear from Figs. 40 and 41, from the point of view of commercial sugar production it is hardly more than a large model, of sufficient capacity however for adequate commercial tests to be made with it. The plant was constructed throughout by Messrs. John I. Thornycroft and Co., Limited, at their Basingstoke works. It has now been shipped to France, and put into commercial operation.

The operation of the plant will best be described with reference to Figs. 3 to 5. As will be seen from these there is a rectangular tank M fixed near the bottom of the main tank or tower A. Part of this tank M is divided off by a perforated plate and into this part B the sliced beet falls direct from the slicing machine. Hot juice, or "sirop," is maintained at a constant level in this tank by means of a ball valve C, which is connected to a pipe leading from the bottom of the tower. In order to ensure that the juice in this tank M shall always be kept at a high temperature a heater, or calorizator H is introduced in the pipe connecting the valve C with the bottom of the tower. The heater can be seen in Figs. 3 to 5, and also in the general views of the plant given in Figs. 40 and 41, page 328. It will be seen from these latter figures that the calorizator is actually somewhat longer in proportion to the tower than is indicated in the outline views. Fixed at the bottom of the tower and axially with it there is a cast-iron cylinder D, the piston of which is operated by an hydraulic ram, and at the top of this cylinder there is a large mushroom valve, also operated hydraulically by the ram L. The cylinder is connected to the tank M by the passage which can be seen in Fig. 3, and this passage is arranged so that it can be opened and closed by means of an hydraulically-operated slide valve. The arrangement of the piston and mushroom valve with their operating hydraulic cylinders will be understood from the enlarged detail given in Fig. 6, on Plate XVI. The slide valve can be seen to the right of and close against the cylinder in Fig. 3. The scale is somewhat small, but the arrangement should be quite clear from the details of the cylinder given in Figs. 7 to 12. The face on which the slide valve works is clearly shown in Figs. 7 and 8, while detail views of the slide valve itself are given in Figs. 15 to 17. The mushroom valve is guided by four brackets, details of one of which are given in Figs. 13 and 14. When the piston in this cylinder D descends, a charge of mixed beet slices and hot juice passes from the chamber B and fills the cylinder. The slide valve is then closed, the mushroom valve is opened and the piston rises, forcing the charge of beet and juice into the bottom of the tower. The mushroom valve then closes. It is necessary to prevent air being drawn into the system, as this would be detrimental to the diffusion, and the bottom of the cylinder is connected by a pipe to the tank M, so that when the piston rises the lower part of the cylinder is filled up with juice from the tank. This juice is returned to the tank when the piston descends again.

Diffusion takes place in the tower which is the essential item in the machine. It is 5½ m. high and 700 mm. diameter, and is built up of three sections, each formed from two steel plates rolled and riveted together. A welded angle-iron ring is riveted to the top and bottom of each section and bolts through these angles hold the whole arrangement together. The bottom angle is bolted to a face plate which is approximately 1,100 mm. square. The cylinder D is bolted to the underside of this plate. At the bottom of and inside the tower there is a cast-iron cone-shaped grating, which can be quite clearly seen in Fig. 3. This is introduced to prevent beet clogging the pipe which leads to the

ball valve C by which the tank M is kept filled with juice.

When the tower is in operation it is completely filled with a mixture of beet and juice, so that when the piston ascends and the new charge is introduced the column of beet in the tower rises suddenly. Since, however, juice is led away from the base of the tower to the tank M the column of beet tends to fall again. If this were allowed it would form a pack which would be difficult to raise, and to prevent it a number of screw-blades are carried inside the tower by a shaft which projects down from the top. The shaft and its screw-blades are indicated in Fig. 3. The shaft is supported in a bearing at the top of the tower, and is partially rotated after each rise of the piston by means of the hydraulic ram shown at I, in Figs. 4 and 5. The weight of the beet as it rises is picked up by the revolving screw-blades which prevent it from falling again. A detail cross-section of this hydraulic ram which operates the vertical shaft is given in Fig. 18, on Plate XVI. The snaft is driven through a pawl and ratchet, and the tail rod of the ram is fitted with a buffer spring to prevent jar on the return stroke. Details of the screw-blades are given in Figs. 19 to 21.

During diffusion it is essential to maintain the temperature of the mixture of beet and juice inside the tower. In order to effect this three small centrifugal pumps, indicated by J in Fig. 3, are bolted on the side of the tower. These pumps draw water from the tower and circulate it through external pipes returning it to the tower at a point diametrically opposed to that from which it was drawn out. Steam jets are introduced into these pipes and by means of the valves controlling them any desired temperature can be maintained in the tower. The pipes are furnished with fittings to carry thermometers. These centrifugal pumps, besides providing a means of regulating the temperature are also beneficial in that they keep a steady flow of water in circulation over the beet and thus give more even washing. In order to prevent small pieces of beet from clogging the pumps, large area gratings are placed between them and the tower on both the suction and delivery sides. The pumps, as will be seen from Figs. 40 and 41, page 328, are driven from an electric motor by belts stepping from one pump to the next. Details of one of the pumps with the impeller and driving pulley shown separately are given in Figs. 22 to 25, on Plate XVI. Figs. 26 and 27 adjoining these show details of the cleaning door which is situated near the bottom of the tower and can be seen in Fig. 3.

It will be evident from what has already been said that the strongest juice is at the bottom of the tower, and that as the beet gradually rises it comes into a weaker solution so that all the sugar it contains is gradually given up. The fresh beet as already explained, enters at the bottom. It leaves fully exhausted at the top the lip shown at K, in Fig. 3, being provided to facilitate its removal. As the beet travels from the bottom of the tower to the top, the juice travels from the top to the bottom. The juice ready for further treatment is drawn off from below the cone-shaped strainer, and the fresh water is fed in at the top. To maintain a constant level a tank F with a float is fixed at the top of the tower as shown in Fig. 3. This float controls a valve G in the fresh water supply pipe. This pipe terminates in a ring with small perforations so that the supply water falls into the top of the tower in a fine spray.

The operation of the plant is continuous, sliced beet and water being supplied as required and full strength juice being drawn off. Attendance is required in connection with the beet supply and the drawing off of the juice, also in connection with temperature regulation. All other operations are automatic. As will have been understood from our description, there are four operating rams in connection with the plant. These control the piston, mushroom valve and slide valve of cylinder D and the movements of the vertical shaft carrying the screw-blades. The operation of these various rams is controlled in the correct cyclic order by a cam plate which is continuously rotated by an electric motor. This cam plate operates four distributing valves which, in turn, control four oil-operated relays which connect the hydraulic cylinders to pressure or reverse as may be required. A general view of this control gear is given in Fig. 39, subjoined, while various details are given in Figs. 29 to 39.

This control gear is self-contained, and can be fixed in any convenient position away from the diffuser, the only connection between the two being the high-pressure water pipes. The gear is not indicated in Figs. 3 and 4, but it can be seen in the foreground of the plant in Fig. 41. The cam plate which controls the operation of the distributing valves lies in a horizontal plane, as will clearly be seen from the plan view of the apparatus given in Fig. 29. Around and above its upper surface, which carries the cam grooves, the distributing valves are arranged. They will clearly be seen in Fig. 29, one at the left, one at the bottom and two to the right. Their positions relative one to another around the cam plate depends, of course, on the relative times at which the various rams are required to operate in the cycle. One complete rotation of the cam plate corresponds to one complete cycle of the diffuser. Some details of one of the distributors are given in Figs. 30 to 35, and it will be understood that the rotation of the cam plate moves the valve rods of these distributors in and out and so controls the pressure oil supply to the relays. The oil supply is at 5·6 kg. per square centimetre and is obtained from a small oil pump driven by the same motor which drives the cam plate. The pump can be seen in Fig. 39. A partial cross-section view of one of the relays with a separate view of the hydraulic valve is given in Figs. 36 and 37. The oil supply works on the large diameter piston, and the movements of the latter control the water supply to the rams. The relays are shown mounted round the cam plate in Fig. 29, but actually they are mounted in a row on the base-plate of the tower, as shown in Fig. 39. A detail of the grooving of the cam plate is given in Fig. 38.

We need not again point out that this Thornycroft apparatus is a continuous diffuser, but the detail explanation of its operation which has now been given will have brought out more clearly the advantages as compared with the ordinary multi-cell

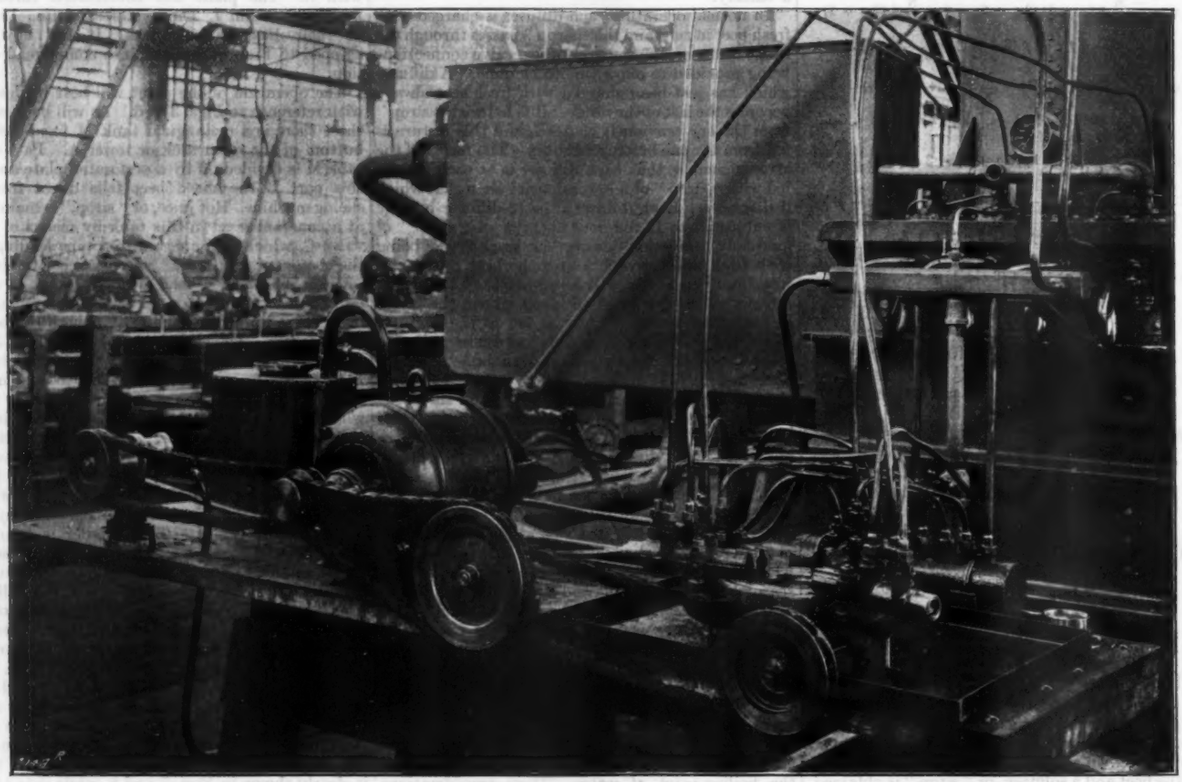


FIG. 39. GENERAL VIEW OF CONTROL GEAR.

diffuser. A point which we did not mention in our earlier brief description of a multi-cell battery is that in plants of that class two cells must always be cut of action, so that in a 16-cell battery, 12½ per cent. of the plant is always non-operative. No such condition of course applies with a continuous diffuser. A further point which may be mentioned is that in a multi-cell plant diffusion takes place in steps and the result can only be perfect when a large number of cells are employed, because the beet slices at the top and bottom of each cell are not equally exposed to the stream of juice which has to remove the sugar from them. In the continuous machine the beet slices are moving in a contrary direction to the flow of the juice and must finally come to a place where, when they are low in sugar content, they come in contact only with pure water and thus yield the last of their sugar. A final point which may be mentioned is that in a multi-cell diffuser unless a special compressed air system is employed to force the liquid from the cell to be emptied, a large amount of sweet water must be wasted. In the single-cell machine the beet leaves the water before it is discharged and consequently the water drains back into the machine. As already stated trials with the Thornycroft diffuser have proved very satisfactory and have shown that diffusion is in every way as complete as with the multi-cell system, while it will be quite clear from the description we have given that in first cost and labour charges it should compare very favourably with its older rival.

THE INSTITUTE OF METALS.

(*Concluded from page* 303.)

ON the members reassembling in the Hall of the Institution of Mechanical Engineers, in the afternoon of Wednesday, the 8th inst., the reading and discussion of papers was proceeded with.

THE INTERNAL MECHANISM OF COLD-WORK AND RECRYSTALLISATION IN CUPRO-NICKEL.

The first paper taken on that occasion was the one having the above title, by Mr. Frank Adcock, who read it in abstract. We commenced the reproduction of this on page 305 of our last issue, and give the concluding part on page 340 of the present one. Mr. Adcock stated that he had selected cupro-nickel for his investigations since he had plenty of that metal available; it could, further, stand a large amount of work, it polished easily and he had ready means for etching it.

Dr. Johnson, who opened the discussion, congratulated the author for his work and for having found an alloy which lent itself to recrystallisation in various stages. He (the speaker) had worked with copper, and dealing with the author's statement to the effect that the cupro-nickel showed a coarse structure after drastic annealing, he (Dr. Johnson) thought that was a great advantage, for the coarse crystalline material was better for examination purposes than the fine crystalline one. Here Dr. Johnson gave lantern slides and pointed out the close relationship which existed between his own work and the author's; the same phenomena were exhibited; the rolled out crystals showed etch bands lying 40 deg. to the direction of rolling and were reversed from grain to grain; also etch bands in the cold rolled beta decrystallisation along the planes of slip, and other points of similarity.

Miss Elam found the series of photographs to be an excellent one; these coupled with the good explanations in the paper, afforded further evidence in regard to the recrystallisation of metals, and supported the conclusions of all previous papers dealing with the same subject, namely, among others, that recrystallisation after work was associated with some interruption in the crystal structure. She had always found that recrystallisation started in the boundary, and others had also found that that was the case. She suggested that the etch bands were very fine twins; she had examined pure silver and had found quite a number of such striations which were really fine twins. Here Miss Elam exhibited slides showing the striations in silver to be very similar to those pointed out by the author, and there was no doubt but what they were very fine twins. On annealing recrystallisation followed these bands as was the case with the author's metal. The author had concluded that the crystal orientation was altered by "bending," but in his explanations of the photomicrographs he did not confirm the point. Oblique illumination would better throw up the structure, and Miss Elam asked whether he had tried oblique illumination. There was no evidence of "bending," the structure was parallel throughout; orientation did not vary in an abrupt manner. With reference to the author's conclusions, several of which were in accordance with the observations made in the Carpenter and Elam papers, Miss Elam expressed the view that a stage had not yet been reached at which one could theorise upon these matters.

Dr. Rosenhain found the photomicrographs most interesting. He disagreed with the last speaker and thought one could well theorise on the subject and not merely accumulate dry facts. The author's findings were confirmed by other work carried out at the National Physical Laboratory on other alloys, also homogeneous in solid solution and also having the etch bands strongly marked. He illustrated this work by a number of slides showing slip bands and said he did not think there was real twinning in these bands, but what occurred was dislocation of crystal orientation. The band was somewhat like a crystal boundary. Dr. Rosenhain also drew a comparison with the occurrence in nickel steel. In regard to "bending," if a large crystal were taken and "bent," the doubled one would have a change of orientation. He illustrated his remarks by a sketch of a crystal on which he marked cleavage planes, if the crystal were bent pressure occurred at one point of the planes and tension at the other point; he showed the amorphous layers to be thick on the tension side and thin on the opposite pressure side.

Dr. F. C. Thompson agreed with Dr. Rosenhain in thinking that the structure could not be Neumann lamellæ. In regard to "bending," in nickel-silver slip bands did bend as shown by the author; there was a definite bend at the crystal boundary. Dr. Thompson explained by a sketch how it was possible to get two different types of crystal deformation; in rolling there occurred a marked shear along certain planes.

In the course of his reply to the discussion, Mr. Adcock said he was glad the work by Dr. Johnson gave somewhat similar results to his own, but the straight line in brass, shown by Dr. Johnson, had not much in common with the "fuzzy" lines he (the speaker) had shown in cupro-nickel. He (the speaker) had gathered much inspiration and help from the two Carpenter and Elam papers dealing with aluminium. In the matter of the Neumann bands, he was not an authority, but there was more in them, he thought, than appeared. When examination was made under high magnification they were not straight but serrated. He had not tried for difference in orientation by oblique illumination in cupro-nickel. Concerning the "bending" of the crystal structure, the patches where bending took place were only seen after careful examination. Cupro-nickel etched up better than other metals, and better showed orientation by etch pits. He noted Dr. Rosenhain's explanation as to amorphous material in "bending." With reference to the sketch by Dr. Thompson, coring was not visible after annealing when the material was etched.

THE EFFECTS OF IMPURITIES ON RECRYSTALLISATION AND GRAIN GROWTH.

The second paper read at the meeting on Wednesday afternoon, the 8th inst., dealt with the "Effects of Impurities on Recrystallisation and Grain Growth," by Major C. J. Smithells. We reproduce it in abstract in page 342, and need not refer to it specially here.

Dr. Carpenter, who alone took part in the discussion welcomed the paper as being the first one presented by the Research Laboratory of the General Electric Company. It gave an interesting instance of rapid crystal growth, in rather special conditions. He would like the author to state how he had measured the temperatures. The metal was admittedly unhomogeneous; in the first instance it was powder which was treated as the author explained, it was pressed, sintered, swaged and drawn into wire. The author had referred to a statement in one of his (the speaker's) papers written in collaboration with Miss Elam, to the effect that "in worked and annealed metals the impurities either passed into solution or remained scattered throughout the crystals quite independently of the boundaries," and added that the statement required modification. Dr. Carpenter maintained this statement. He also found that the author's general theory was based upon the hypothesis that his (the author's) special case was applicable generally. As Miss Elam had said earlier in the day, we wanted more facts rather than theory, and it was in such instances as the present one that her remark was specially applicable. Dr. Carpenter saw nothing in favour of Mr. Smithells' said hypothesis in the third part of his paper. The only metal showing any appreciable vapour pressure was zinc. It appeared to him (the speaker) that no measurements of vapour pressure were made at the temperatures at which the metals were studied. The paper made four assumptions. That an amorphous phase existed between crystals and that theory would not explain everything; this was not established. In the second place, that large crystals dissolved smaller ones; in this connection Miss Elam and he (the speaker) had shown that was not the case. In the third place, the author referred to the crystal lattice, but his remarks in this connection were not in agreement with papers on X-rays. Finally the author brought forward the strain hypothesis and asked whether there were any basis for assuming that a strained crystal had a higher vapour pressure than an unstrained one, and said at the same time that there was at present no evidence as to the arrangement of the molecules within a strained crystal. Exception could therefore be taken at all these four points.

In his reply, Major Smithells said he had endeavoured to account for the facts of crystal growths which had not yet been accounted for. Dr. Carpenter had not put forward a constructive argument. The temperatures were registered by photometry, the lamps were put on the required voltage to give the desired temperature. In regard to the migration of the impurities to the grain boundaries, in the author's experiments the large grains contained thoria, and thoria went to the boundaries, none insoluble remained in the body of the crystal. Dr. Carpenter had taken too literally his (the author's) references to vapour pressure, and the latter showed by a sketch on the blackboard how vibration increased with temperature and the difference of the occurrence and behaviour in solids and liquids. In the matter of the amorphous phase he would not enter any further at that stage, and if Dr. Rosenhain did not support that theory in the present discussion, he (the speaker) would not. He still believed the majority of workers were agreed that large crystals absorbed small ones. (Here Dr. Carpenter said his and Miss Elam's work related to material which was unstrained.) Continuing his reply, Major Smithells added that as annealing was proceeded with the grains continued growing. He had seen the paper on X-rays analysis and there seemed to be no doubt that when strained the crystals got slips "in little blocks," and in his (the speaker's) theory there was some residual strain "in little blocks." He asked Dr. Carpenter why he postulated that a strained crystal did grow. (Dr. Carpenter replied that he was carrying out further experiments and would publish the results of these only when ready.)

FURTHER STUDIES IN SEASON-CRACKING AND ITS PREVENTION. CONDENSER TUBES.

The third paper taken at the meeting on Wednesday morning was the one having the above title, by Dr. H. Moore and Mr. S. S. Beckinsale. We reproduce it on page 337. In presenting it, Dr. Moore confirmed the remarks he made during the morning meeting and said he felt dubious as to the advisability of going to the high temperatures mentioned by Dr. Bengough, as the effect might be a reduction in the hardness of the tubes. Dr. Rosenhain's suggestion as to the removal of stress in the tube was a good one, and the removal of stress might have a favourable effect on resistance to corrosion.

Mr. R. T. Rolfe said splitting might occur in condenser tubes, and the authors' paper gave methods of preserving them from that occurrence.

In this connection, in the address he delivered in 1914, Engineer Vice-Admiral Sir Henry J. Oram said that in 1908, when the condenser tubes at work at sea in the British Fleet numbered about 2,500,000 only 21 failed by splitting, while, in 1913, when the number was about 3,800,000, only 16 failed by splitting. Admiral Oram, on the same occasion, said that "the ideal to work for was to reduce the failures to zero," but added that "beyond a certain point further tests, restrictions and precautions became so expensive as to be not worth the cost involved, in which case we must be satisfied with the success already achieved." He (the speaker) took dozens of tubes and immersed them in solutions of ammonia and of mercurous nitrate, and no splitting occurred. Further evidence was therefore needed in regard to the splitting; the annealing of all tubes meant increased cost.

Admiral Goodwin recalled that two years ago the possibility of removing internal stress in the tubes without unduly reducing hardness had come up in discussions. Dr. Moore and Mr. Beckinsale undertook the task of investigating the point, and the result of their work was the present paper. He (the speaker) was not quite certain as to whether this result was practically going to be all that was wanted, but it would go a long way towards it. He congratulated the authors on their work and conclusions. Splitting occurred in the tubes, although it was not very frequent; there were one or two cases during the war and these took place in circumstances of extreme difficulty. The 21 cases of splitting out of a number of several million tubes might be in 21 different ships, and this would give an idea of the gravity the occurrence might assume. However, the number of condenser tubes which gave out for all causes was a very small one relatively; in the majority of ships there was no condenser tube failure, but when this did occur it gave no end of trouble. There were occasionally "epidemics" of failures, both at home and in distant parts, such, for example, as in the China Station. He (the speaker) had great faith in Dr. Bengough's remedy of pre-oxidation. Tubes were going to be treated both on Dr. Bengough's and on the authors' recommendation of low-temperature annealing in order to ascertain how they would stand up to their work. He was glad the researches of the Institute enabled the Navy to undertake these tests. In the meantime, since the authors and Dr. Bengough did not agree together he thought they should work together in collaboration and arrive at a joint conclusion on the points in which there was difference of opinion. He asked how the pre-oxidising process could be carried out on tubes in lengths of, say, 15 ft.

In the course of his reply, Dr. Moore expressed the view that Dr. Rolfe's remarks had been answered by Admiral Goodwin. The authors' treatment was not a very expensive one, and it did not decrease the strength of the tubes. The tests Admiral Goodwin had mentioned as going to take place would be of great importance as showing the value of the treatment and its freedom from drawbacks.

This concluded the proceedings of the first day.

The Rate of Combination of Copper and Phosphorus at Various Temperatures.

On the members reassembling on the morning of Thursday, the 9th inst., the first paper read dealt with the "Rate of Combination of Copper and Phosphorus at various Temperatures," contributed by Dr. C. A. Edwards and Mr. A. J. Murphy. We shall reproduce it in abstract in a future issue.

The discussion was opened by Dr. F. Johnson who said the importance of the subject was greater than was generally imagined. Phosphor-copper was a most efficient deoxidiser; unsound copper could be made sound, or brittle copper could be rendered tough by a judicious addition of phosphor-copper, and a reliable method of producing the latter was welcome. For making small quantities of phosphor-copper, on a small scale, his (the speaker's) method, which was very satisfactory, was by means of a tube of ordinary salamander placed inside a covered crucible and containing rod phosphorus, the inside tube containing the red phosphorus being immersed in molten copper contained in the crucible, the phosphorus being made to pass through the molten copper surrounding the inside tube. The loss of phosphorus was very small.

Mr. C. Billington said he had been making phosphor-copper for the last forty years commercially, with phosphorus content up to 16·5 per cent. There was risk and trouble in the manufacture, and no chance of cheapening the product. He confirmed that it was a good deoxidiser. Phosphorus in copper brought on brittleness. Tin was the metal used for hardening and phosphor-copper for deoxidising and obtaining a better alloy.

Dr. F. C. Thompson emphasised the great difficulty of the problem dealt with by the authors, and this should be borne in mind when considering their results. He asked for further information on the authors' curve giving phosphorus content and temperature, in which they plotted their results and the corresponding results obtained by Heyn and Bauer, and in which, also, the dotted line pointed to a great solubility of phosphorus in the solid state; this latter was higher than would have been expected. The evidence for the compounds was not great, since the authors had queried them in the diagram in question. Notwithstanding this, their work on the theoretical side was very important. The formula they had quoted for solids dissolving in liquids held to some extent for many reactions, but he (the speaker) did not find that it applied in the authors' case. They had shown that the more simple expressions were not sufficient for metallographic work, this was very important and on this point they were to be heartily congratulated.

Dr. Edwards was sorry that Mr. Billington, in his remarks, had not elaborated on the dangers which attended the making of phosphor-copper. One of the objects they (the authors) had in mind was from a practical point of view to arrive at the temperatures which corresponded to the best work coupled with a minimum loss. He was glad to hear the complimentary remarks made by Dr. Thompson. The dotted line on the left side of the diagram which the latter had referred to as being the soluble phosphorus in the solid copper was only provisionally put there. They (the authors) did not go so far as was intimated, but would say that solubility was at least as shown by the dotted line. The line represented the composition of the solid which would be obtained on heating to the corresponding temperature for an indefinite period.

Some Cases of Failure in "Aluminium" Alloys.

The second paper taken on Thursday was the one having the above title, by Dr. Rosenhain, which we reproduced on page 308 of our last issue. As will have been seen, its object was to point out that some alloys which underwent distortion and disintegration of the kind illustrated usually consisted mainly of zinc and were not properly described when stated to be aluminium alloys.

The discussion was opened by Dr. D. Hanson, who said he agreed with Dr. Rosenhain entirely, adding there was no desire at all to condemn zinc alloys absolutely, concerning which enough was known to heat treat them so as to avoid such disintegration as pointed out.

Professor Turner directed attention to the analogy which existed between zinc-aluminium alloys and zinc-copper alloys, both showing remarkable expansion under certain conditions. Dr. Rosenhain had rendered good service in pointing out that many alloys, called aluminium alloys, were not such, but zinc alloys, and his remarks would remove some of the reproaches which had wrongly been cast on the former.

Mr. Billington asked whether a cause of the distortion was not the small percentage of tin present in the said alloy.

Dr. Rosenhain, replying in the negative to Mr. Billington, said tin was not an advantage to the alloy and had nothing to do in the matter. It was true that heat treatment could be carried out, but heat treatment was expensive, and the alloy was used in the particular case because it was cheap. If heat treatment were ever contemplated, it would be better to leave the alloy referred to and take another one.

Some Mechanical Properties of Nickel-Silver.

The third paper read dealt with "Some Properties of Nickel-Silver," contributed by Dr. F. C. Thompson and Mr. E. Whitehead. It formed a study of the effect which annealing at different temperatures and the different rates of cooling after annealing have upon the tensile properties, the Arnold alternating stress values, and the Erichsen values of hard-rolled alloys containing 10 per cent., 15 per cent. and 20 per cent. of nickel. All the tests showed the influence of the change which occurred at 300 deg. C., and, in addition, revealed another temperature range at about 550 deg. C., in which abnormal results were obtained. The best annealing range for the 10 per cent. nickel alloy was between 725 deg. and 825 deg. C.; for the 15 per cent. nickel alloy between 700 deg. and 800 deg. C.; and for the 20 per cent. one about 800 deg. C. Quenching from the annealing furnace had no markedly beneficial effect. One of the most remarkable features of the results was the high temperature to which the alloys could be heated without deterioration, especially when the sample was protected from oxidation. The furnace gases played a very important part in the production of "burnt" material; this, incidentally, was a point in favour of the salt bath for this type of annealing. The Erichsen tests especially all showed remarkably good results, even after annealing at as high a temperature as 850 deg. C.

The discussion was opened by Mr. F. S. J. Pile, who exhibited a number of samples, and emphasised an important point commercially, not covered by the paper, namely the surface which was obtained on the metal. Some of the samples he showed had similar Erichsen values, but some were found useless for commercial purposes owing to their surface. It was important to have the required Erichsen value, with ductility for undergoing the necessary drawing, and not to double the cost of the product by having to burnish to any great extent; moreover, no amount of polishing would bring the metal to the requisite surface. Such subsequently polished metal, as a commercial proposition, was quite out of the running. The authors might not have come across this trouble which faced manufacturers, namely, this necessity of obtaining a metal having the right ductility for working up, and at the same time the right surface also. He asked how the annealing was timed. If the authors could solve the difficulty he had alluded to, they would confer a service of very great value indeed to manufacturers. If the Erichsen value were much over 11 there was this "surface danger" to be reckoned with.

Mr. W. R. Barclay expressed the hope that the authors would continue their work, and the fear that there was danger in annealing to so high a temperature as 800 deg. C.; this seemed a very high temperature, and one which might result in difficulties.

Dr. D. Hanson asked for further information on the authors' statements as to the existence of critical points at 300 deg. and about 550 deg. C., since although the one at 300 deg. C. was very marked, the other was not so marked; also whether they had given attention to the question of the part that might be played by impurities, since he had found that even slight impurities might have a great influence. He noticed in the authors' analysis that carbon, sulphur and iron were in appreciable quantities in the materials they used.

Mr. W. B. Clarke found that the paper raised the old question of annealing, and added that he agreed with the remarks by Mr. Pile concerning the surface of nickel silver; from his own experience he thought the non-ferrous metals industries would save very large amounts indeed by bright annealing all their products. Pickling and polishing accounted for a very high loss of metal, and this loss would not occur with bright annealing. But nickel-silver was difficult to anneal. The authors mentioned for this a muffle furnace; was this closed or open? If open, with gas or coke-firing, there would be a large amount of scaling. If closed, great pains had to be taken that there be no cracks, for on an average muffle furnaces cracked, and unless the cracks were very carefully filled up curious results happened; the gas penetrated through the cracks, and in some instances he had seen the metal inside become quite rotten. There was also great difficulty in keeping carbon from crucibles entering the metal, and carbon had a great

effect on the properties of nickel-silver alloys. He (the speaker) painted the inside of the black-lead crucibles with a coating of very fine clay, this dried on and would stand at least one heat; the carbon penetration in the metal was thereby reduced to a minimum. The authors had given the annealing times as 1½ hours, 3 hours or 4 hours. Was that the total time at which the material was at the maximum temperature, or the time in the muffle, or the time to get up to the heat? If the material were heated up quickly the result would be different from what it would be by heating up slowly. The authors embedded the metal in plaster of Paris; was this in the wet or in the dry state, and was it any better than sand or magnesia to prevent oxidation? Graphite might be used, but it made the work black. The authors' figures for tensile tests of annealed series with 15 per cent. of nickel showed rapid variations from about 300 to about 550 deg. C., and this would seem to point to some unstable condition of the alloy.

Mr. Whitehead replied briefly to the discussion, and said that he was afraid the surfaces of the test pieces had not been very minutely examined. Their chief attention had been paid to arriving at the effects of annealing upon the mechanical properties. In future work they would give the question of the surface all their care. With regard to the annealing temperature of 800 deg. C. which had been reckoned a too high one, this was justified by the results, namely, a greater ductility. In the matter of the critical points, they were quite well marked at the temperatures of about 300 deg. and 550 deg. C. As for impurities, the alloys used were essentially commercial alloys, and their degree of purity was that of everyday alloys; some points, round 550 deg. C., might perhaps be due to impurities, but he hardly thought so. By annealing at 900 deg. C. probably volatilisation would take place to a small degree; burning commenced at that temperature, but 800 deg. C. was a temperature that could be worked to. The muffle was open, but the metal was protected by plaster of Paris. The metal was placed in a tin box, on a bottom layer of plaster of Paris, the metal was then surrounded by the same material, the box being filled up with sand. An ordinary clay pot would not stand the temperatures, and he recommended clay pots such as those used for Sheffield steel. The annealing time was that during which the specimen was actually in the furnace; the muffle was heated up to 750 deg. C., the boxes put in the muffle and then the specified time was taken. For packing the metal, plaster of Paris was the only material used, sand serving to fill up the corners. Magnesia and graphite were not tried.

A Further Study of the Alloys of Aluminium and Zinc.

The next paper, on the above subject, was contributed by Dr. D. Hanson and Miss M. L. V. Gayler. The work was undertaken with a view to investigating further the constitution of the phase known as delta in the diagram of Rosenhain and Archbutt. Preliminary experiments with alloys containing 70 per cent., 60 per cent. and 50 per cent. of zinc, when slowly cooled to 284 deg. C., after prolonged annealing at 420 deg. C., and quenched, were found to be duplex in structure. The inconsistencies between these microstructures and those suggested by the existing diagrams led to a redetermination of the solidus from 81 per cent. zinc to 20 per cent. zinc. The results obtained differed appreciably from those of previous workers; the line representing the peritectic reaction was found to extend up to a composition of 70 per cent. zinc, as against 40 per cent. zinc in previous diagrams. Microscopic examination of alloys, following special heat treatment, disproved the existence of the compound Al_2Zn_3, and showed that the nature of the change in the alloys at the temperature of the horizontal line at 256 deg. C. in the Rosenhain and Archbutt diagram was identical with an ordinary eutectoid transformation; the decomposition of the beta phase leading to the "pearlitic" structure commonly found in the alloys. Further work on alloys at temperatures below 256 deg. C. showed that the solubility of the alpha constituent in the gamma constituent decreased with the temperature. Alloys containing the beta constituent were found to possess the property of age-hardening spontaneously at room temperature after being quenched from above 256 deg. C., while those containing the gamma constituent showed the property, but in a much less marked degree.

The discussion was opened by Professor Carpenter, who said he was interested in the paper as a teacher of metallography. For some years at the Royal School of Mines they gave the fourth year students a study of the diagram of this system. It possessed various merits. The metals were reasonably cheap, and the diagram provided nearly every type of equilibrium that they could study. From time to time, however, as he went round the laboratory, students had shown him structures which he had been unable to interpret, structures in the part of the diagram with which the authors particularly dealt. He had always told his students that he did not consider the structures were capable of explanation by the diagram as it stood, and for that reason, those who were teachers at the Royal School of Mines were deeply grateful to the authors for having carried the diagram to a stage which even now he hesitated to say was the final stage. He was very relieved to see the disappearance of delta which had always troubled him in these explanations and it appeared that the equilibria of the system were now capable of definition in terms of alpha, beta and gamma; he thought that was quite enough. There were one or two points in the new diagram which were interesting. It was very remarkable that the peritectic reaction had been altered to so narrow a range; it now occupied very little more than half the range it did in the former diagram. The points G and H were very close together, and he did not gather that the authors themselves had been able to separate them. The new eutectoid reaction by decomposition of beta was probably, on the whole, the most interesting feature, and the authors were quite justified in pointing out the remarkable analogy to austenite in its behaviour in quenching and subsequent heat treatment. The reaction in this case (the decomposition of beta to alpha plus gamma) was one of extreme rapidity, and in that sense was quite different from the martensitic decomposition which was, comparatively speaking, stable at ordinary temperatures. The only further information now seemed to be by X-ray analysis, and he did not know whether the authors proposed to do any work on these lines. He hoped they would, and that some definite information would be obtained as to the distribution of the atoms and the form of the space lattice of beta as compared with alpha and gamma.

Colonel Belaieff endorsed the remarks made by Dr. Carpenter, adding that a point of importance was as to the eutectoid, and he asked whether microphotographs of this, showing the size, were available, and also whether it were possible to have an eutectoid of globular structure. He expressed his admiration for the very complete manner in which the authors had dealt with the subject and for their excellent illustrations.

Dr. Rosenhain, in the first place wanted to say what the authors had refrained from saying too emphatically, viz., that the paper constituted what he might call an improvement on the diagram of the aluminium-zinc system produced by Archbutt and himself some years ago. That was the kind of thing which, in the progress of scientific knowledge, was anticipated and welcomed, and there was the additional gratification that this new diagram which was certainly more perfect and more complete than his own—and regarding which he and Archbutt had felt a good deal of pride at the time—had been produced at the National Physical Laboratory. The reason why the new diagram should be more perfect than the previous was owing to the advancement of the methods of studying alloys and obtaining equilibria. What was formerly regarded as a very slow rate of cooling would be regarded by the present authors as altogether inordinately fast. The authors dealt in months and weeks, whereas formerly other workers dealt in days and hours. They were able to work with devices like the thermostat described by Haughton and Hanson, and these had mainly rendered possible the researches described in the paper. The paper put on the scrap heap the diagram by himself and Archbutt. The important part of the authors' work was the light it threw on the nature of the transformation which led to the hardening and tempering of these alloys, and it seemed to be strictly analogous to certain phases of the hardening process which occurred in carbon steels. In 1914 he (the speaker) put forward the explanation given in the paper, in regard to the hardening of carbon steels and other alloys hardened by quenching, and that had been well justified by the authors' work. In the aluminium-zinc alloys they succeeded in quenching completely, *i.e.*, in preventing the decomposition of the beta phase during cooling. In other words, the material behaved very much as steel behaved at ordinary temperature. Fortunately for engineering, some of our important materials such as hardened carbon steel, happened to be stable at the ordinary temperatures at which they were used, otherwise we should find quenched steel first hard and then soft in precisely the same way as these zinc alloys. He wished to emphasise that aspect of the work because it was likely to react on a good many other branches of metallography besides the study of these alloys, which in itself was very interesting.

Professor Turner congratulated the authors for the admirable work they had carried out, and said that fifteen years ago he had worked on the same series, because the diagram then given was such a simple one. There was now available another diagram which, perhaps, did not exhaust all the changes, but which certainly gave much more information. It would also afford help in studying a large number of other alloys. Colonel Belaieff had referred to the difference in character of the lamellar and globular eutectics, and it would be interesting to know whether the authors had studied the point in connection with these alloys of aluminium and zinc. It was worthy of consideration that the form taken by the eutectic was affected by surface tension of the two constituents. A very notable progress had been made at the National Physical Laboratory, and both the country and the industry were greatly indebted to it for this piece of most valuable work.

Mr. W. B. Clarke referring to the authors' analysis of the metal they used, asked what impurity came from the crucible, since this might have a great importance.

Dr. J. L. Haughton asked the authors for information as to the Brinell hardness tests measured after quenching, and the time, as quoted in two tables of the appendix. No other data being given, one would take it that the specimens were removed, put to the room temperature, then in the testing machine, and 5 minutes for this since the quenching would seem justifiable. The first hardness figures quoted by the authors were obtained "immediately after quenching," and the next were obtained "15 seconds after quenching"; therefore the authors' "immediately" must mean "immediately." He asked what was the time for the first figures, whether, probably, 3 seconds or 4 seconds. The point had an interesting bearing upon the authors' other statement as to the age-hardening of the constituent beta; in regard to this constituent they say that hardness attains a maximum in a period of 5 minutes in the case of the alloy containing 81 per cent. of zinc and 6 minutes in that of the alloy containing 79 per cent. of zinc. He asked whether the load was left on for an appreciable time after the specimens were removed from the ice.

Dr. Hanson, in replying to the discussion, said the "immediately after quenching" meant about 2 seconds; it was a rather short time, but in this connection he called attention to a micrograph in the paper showing a specimen quenched from 370 deg. C. and etched 1½ minutes after quenching, this would point to the fact that the hardness numbers could be taken in about 2 seconds. The specimens were removed from the ice and the load kept on for 10 seconds. They had found that the hardness number depended upon the time the load was left on. Dr. Carpenter had asked whether they (the authors) could separate the points G and H in their diagram of the system; they could not give a definite composition for the points G and H, they

knew they were close together. They had used the word decomposition in regard to the gamma phase; this, however, was perhaps not wise since it was not the same occurrence as in the beta phase. Dr. Carpenter's explanation of a duplex structure applied to the authors'. He (the speaker) could not say if a definite globular eutectic was formed, but saw no reason why one could not be formed. The authors greatly appreciated Dr. Rosenhain's remarks, and he (the speaker) took that opportunity for stating that all through their investigations they had received great encouragement both from him (Dr. Rosenhain) and from Mr. Archbutt. If it can be shown that their (the authors') present diagram of the system is not correct, they will be most pleased. They agreed with all Dr. Rosenhain had said in amplification of their (the authors') remarks on age-hardening.

THE ASSAY OF GOLD BULLION.

The last paper taken dealt with the "Assay of Gold Bullion," by Mr. Arthur Westwood. It was read in abstract by Professor Turner. In this the author suggests a new method of assay. The method now universally followed of assay by cupellation, inquartation and subsequent parting is very ancient. In the author's method, the assay sample is not cupelled, but melted and balled up under steam or an inert gas. For the usual inquartation, copper was recommended instead of silver.

Mr. Barrs, a visitor, said the method seemed to be a very simple one, and if the author gave a sketch to illustrate it, the paper would gain largely in interest.

On the motion of the chairman all the authors received the thanks of the meeting for their contributions.

The usual thanks to the Institution of Mechanical Engineers for the kindly loan of their premises terminated the proceedings.

AMERICAN WARSHIP PRACTICE.*

By S. V. GOODALL, R.C.N.C.

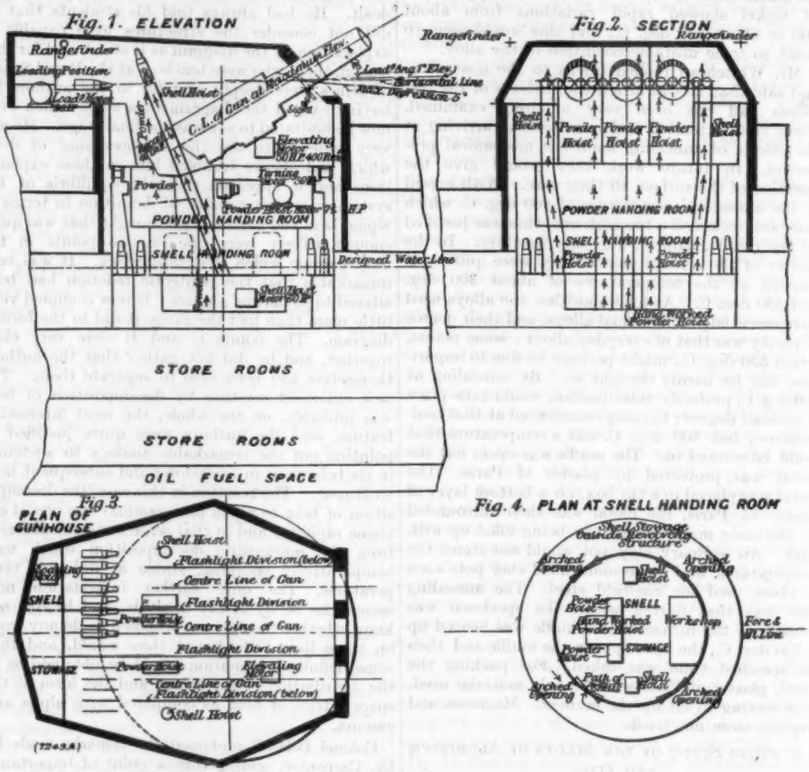
THE title of this lecture calls for an apology, for it would be impossible in the short time available to give an account of American warship practice that would do justice to our friends across the sea. I shall make no reference to submarines or naval aircraft except to note that, so far, the United States authorities have deliberately refrained from establishing a separate Air Force; airships, seaplanes, flying boats and naval aeroplanes are produced by the United States Navy Department, produced with success, and with a single eye to the service of the Fleet.

I shall deal first of all with recent American battleships, and principally with the U.S.S. Tennessee, the first vessel, in the opinion of United States officers, to embody all the principal lessons to be learned from the battle of Jutland and general experience during the late war. In her main features this vessel resembles the latest American battleships; the leading particulars are as follow:—

Length on water line...	600 ft.
Maximum breadth ...	97½ ft.
Draught at normal load	30 ft. 3 in.
Normal displacement	32,300 tons.
Main armament ...	Twelve 14-in. guns, in four triple turrets.
Minor armament ...	Fourteen 5-in. guns, in an upper deck battery. Four 3-in. H.A. guns. Two 21-in. submerged torpedo tubes.
Protection	13½-in. belt over the main citadel reduced below the water line to a minimum thickness of 8 in. On the top of this belt is a deck 3½ in. thick.
Speed	21 knots; actually 21¼ on trials.
Shaft horse-power ...	28,500; actually 30,000 on trials.
Oil fuel capacity ...	About 4,500 tons.
Radius of action ...	About 12,000 sea miles at a speed of about 15 knots; this figure is given with some diffidence, as the estimate is based on published data after making due allowance for fuel consumption for auxiliary purposes.

In looking at this ship the British eye at once would be attracted by her outstanding American characteristics—the lattice masts; the clipper bow with the centre-line hawse pipe for the sheet anchor; the triple turrets with their flat roofs free of hoods or openings and projecting long base rangefinders; the large air intakes forward of the fore funnel down which all the air for the boilers and engine rooms is taken; the two boat-hoisting derricks and the long but narrow outstanding armour belt.

Of these features the lattice masts are perhaps the most striking. When first adopted there is no doubt such a type of mast neatly solved the problem of carrying signal and wireless yards while leaving the deck free of stays and shrouds and absorbing little weight, but it has not been altogether successful in practice. Its form is that of a hyperboloid of revolution built up of long hollow rods secured to a ring on the top deck. It does not lend itself well to supporting the heavy tops which have gradually been adopted for gunnery purposes in most navies. The attempt to add such fittings led to disaster in the U.S.S. Michigan. The fore mast of this ship buckled when the vessel was rolling heavily during a storm and collapsed with fatal results to a number of men. Peace trials have indicated that it will stand up well against shell fire, but I am doubtful whether it is equal in this respect to the tripod mast. The method of support is such that if the deck to which it is secured were severely damaged the mast might go by the board; this actually happened during some bombing trials of the old battleship Alabama.



There are several interesting items of equipment which are not visible. The anchor and capstan gear is driven, as is the usual American practice, by electric motors. I witnessed the operation of similar gear in the New Mexico and was not very favourably impressed. The two motors have complicated arrangements for control, the gear is heavy and does not possess that degree of adaptability which is considered necessary in the British service. The steering gear is electro-hydraulic; there are two main motors operating pumps of the Waterbury type which deliver oil into cylinders in which are rams connected to the crosshead. The motors are situated right aft in the compartment forward of the steering gear. I saw similar gear in operation in the New Mexico, and considered it a very good arrangement, although in that ship there were various auxiliary methods for operating the rudder in the event of a breakdown of the main motors or main electric leads which, in my opinion, involved unnecessary complications.

One word about accommodation. Before I had any personal experience of American ships I held the view that in matters affecting comfort our ships came second. I no longer hold that view. In certain respects United States vessels are superior; they are provided with a laundry, a reading room for the crew, a ladies' retiring room and arrangements for general messing; but in regard to space for both officers and men, particularly the former, in regard to ventilation, sanitary fittings and washing accommodation, we have nothing to learn from American practice.

The 14-in. triple turrets of the Tennessee (see Figs. 1 to 4) illustrate the latest American practice. The mounting is on the usual principle of a turntable inside an armoured barbette. Incidentally the armour of the barbette has no plating or framing behind it so that weight and space are saved. At the level of the upper roller path is a complete deck recessed for the recoiling breech end, with the result that the powder-handling room below is entirely shut off from the gun-house and is thus completely protected from the effects of a shell burst above, provided the hoists are not perforated. Below this compartment is the shell handling room. A number of shells are stowed on their bases on this platform, which is very close to the platform of the fixed structure supporting the ring bulkhead. In the space just inside the ring bulkhead and between its stiffeners, the bulk of the shells are stowed; these, too, stand on their bases. To transport these shells to the bottom of the shell hoists they are rotated on their bases through openings in the circular bulkhead of the mounting on to the handling-room platform and then parbuckled in a similar manner through the compartment to the hoists. The turntable extends one deck farther down to the magazine level. There is no revolving trunk extending down into the hold and there is no shell room. A few reserve shells are stowed below, but they can only be brought into the turret slowly when the mounting is not being operated.

The guns are mounted very close together in independent slides and the trunnions are close to the front shield plate. Loading takes place at a fixed angle. In the Tennessee, the maximum angle of elevation is 30 deg. and depression 5 deg., but in the latest ships I understand these angles are 40 deg. and 3 deg., respectively. To economise in width of turret the breeches of the guns do not rotate about a vertical but about a horizontal axis downwards. The gun is provided with a spring recoil. Each is separated from the other by a longitudinal bulkhead which is, however, too light to be of any protective value. The rear of the gun-house is partitioned off to form an officer's control position, the rangefinder is just forward of this bulkhead. The sights are below the guns; the roof is entirely free of hoods or openings.

The turret is trained by a 50-h.p. constant-speed motor driving, through variable speed gear, a hydraulic motor connected to the training pinion; the training rack and the lower roller path are formed out of the same casting. For elevating the guns, three 50-h.p. constant-speed motors are fitted which drive through variable-speed gear, hydraulic motors that operate the elevating screws; a complicated arrangement of clutches and cross-connections is provided to enable any motor to elevate all three guns. Two 90-h.p. motors operate, through variable speed gear, the chain rammers and the powder hoists; each motor is of sufficient capacity to serve the three guns. The shell hoists are of the step-by-step type and are operated by a 60-h.p. motor. For most of the operations small auxiliary motors are installed driven from storage batteries in the turret.

Particular attention is directed to the stowage and supply of shells and ammunition. When ready for action, a number of shells are on the loading tray and under the control officer's station, some are in the hoist and handling room, while the remainder readily available, are in the fixed structure. There are two shell hoists to the three guns, the supply for the centre gun passes behind the wing gun through the longitudinal bulkhead. From the magazine to the powder-handling

* Lecture delivered to the Portsmouth Engineering Society, January 31, 1922.

room there are two cordite hoists; at this level the charges are transferred to the three hoists, one for each gun.

In commenting upon these turrets a constructor finds it difficult to be impartial. From his point of view they are excellent. The absence of shell rooms and the high position of the magazines gives him an opportunity to shorten the citadel and economise considerably in weight. In the case of the after turrets the problems arising from the conflicting claims of machinery and armament are eliminated. Space, and consequently important target area and weight, have been reduced to a minimum. The 14-in. 50-calibre triple mounting, with guns firing shells of 1,400 lb. weight and having a muzzle velocity of 2,800 ft.-seconds, is enclosed in an armoured barbette of 31 ft. internal diameter and the revolving structure (complete with shells) weighs only 980 tons. There is, however, another side to the picture. A price has to be paid for all these economies; its total can be gauged from the following:—

The trunnion is close to the front shield plate with the advantages of a small gun port and a reduction in barbette diameter, but with the disadvantage that a blow on the front plate may damage the trunnions and jam all three guns. The guns are very close together, with the advantages of small barbette diameter and less whip when a wing gun is fired, but with the disadvantage that to get at the trunnions for examination and overhaul, the front of the shield must be dismantled. Shells and cordite are close to the loading position so that time and power necessary for their transport are reduced, but the magazines are consequently imperfectly protected against long-range fire. The method of shell handling may damage the fuzes, it may break down in a seaway and is dangerous for the *personnel*. Space has been saved by accepting only two shell hoists for three guns, with the result that supply to the centre gun is not so good as to the wing guns. The guns are light and long, but American officers have told me that they might accomplish more accurate shooting with a heavier, stiffer weapon. Then, again, reduced space has resulted in crowding the machinery which is more than absolutely essential, owing to duplications and stand-by fittings; as a result, it is difficult to examine and overhaul parts, and the *personnel* is cramped. A clear flat roof is a good feature, but the sights are in a very poor position and, in fact, for the forward turrets they would be useless in bad weather.

Naturally, in studying these turrets the question arises, has electric power any advantage compared with hydraulic power, the use of which is time-honoured British practice? It will be seen that there is no equivalent to the space necessary for taking hydraulic pipes into the mounting, and, of course, no provision has to be made in the vessel for hydraulic engines. On the other hand, the electro-hydraulic machinery in the mounting leads to the congestion already referred to. It is claimed that hydraulic power is more reliable and positive, and less likely to be adversely affected by the shock of firing or of impact from enemy projectiles. In my opinion a definite statement on this score could only be given by one with long experience of both systems. I have been present at only two firings in United States battleships. In one case, the gun trials of Mississippi, careful observations were being made on the structure of the mounting and supports so that just before actual firing the various motors were stopped; in the other ship, New Mexico, the noise of the motors and machinery was disconcerting, especially that from the loading motor near the officers' control position. This ship, later on, got into very bad weather, and a good deal of water from seas breaking over the forecastle entered the foremost turret and damaged the elevating motors just below the gun ports.

A few remarks on triple *versus* twin turrets seem desirable. If the fire from, say, six guns in two triple turrets were as accurate and rapid as that from six guns in three twin turrets, then there is no doubt that the former would be the better arrangement. The "too many eggs in one basket" argument would be far outweighed by the economy in weight and space. The whole difficulty lies in designing the triple turret to give accurate and rapid fire. Almost naturally shell and ammunition come up the centre of the mounting, and over this sits the centre gun. So far as I see it, that is the inherent difficulty and, in my opinion, clever as this design is, a sure and sustained rapid supply to the centre gun has not been provided.

The question of accurate fire from triple turrets is a very complicated one. The old theory that the wing gun caused a jump which produced error in deflection is now seldom mentioned. I have actually measured this jump and it is quite small. When I was in the United States, the shooting from these triple turrets was not giving entire satisfaction, and the theory then held was that the guns were so close together that the flight of one projectile was affected by the discharge from the neighbouring gun. To overcome this defect a short delay was arranged between the three discharges, but still the authorities were not thoroughly satisfied. The theory was then advanced that this delay was sufficiently long to affect the elevation of the neighbouring gun. Research on this matter was then proceeding.

The next interesting feature in the Tennessee, the electric propelling machinery, is illustrated in Figs. 5 and 6. Steam is supplied by eight oil-fired Babcock and Wilcox boilers fitted with superheaters. Each boiler is accommodated in a separate watertight compartment situated on the outboard side of the turbo-generator rooms, so that the steam pipe system is simple and direct and the danger of a failure in this supply is very remote. The boilers deliver steam at about 250 lb. per square inch gauge pressure, with 15 deg. to 20 deg. of superheat, at the turbines.

There are two engine rooms, each containing a turbo-generator kept cool by a separate fan. The main con-

Fig. 5. PLAN OF ENGINE ROOMS ABOVE FLAT

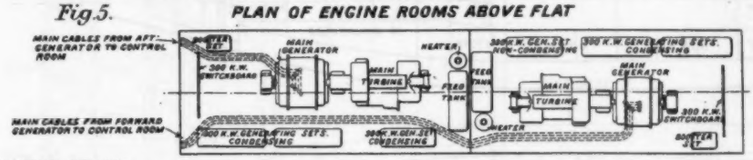
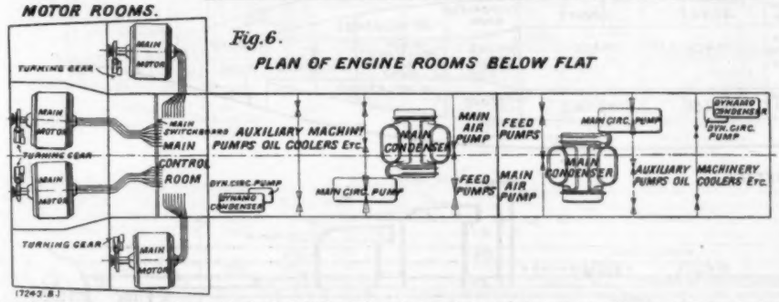


Fig. 6. PLAN OF ENGINE ROOMS BELOW FLAT



denser is just below the turbine, and the main air and circulating pumps are also at this lower level, as well as various auxiliaries. In each engine-room on the upper flat are three 300-kw., direct-current generators driven by geared turbines. Two of these exhaust into their own condenser and one exhausts into the main turbine; this is the exciter providing the field for the main generator and current for all the engine-room auxiliaries necessary to the main propulsion, so that the main and auxiliary circulating and condensate pumps, the lubricating and governor oil pumps, oil cooler circulating pumps and the main ventilating fans are motor driven. On the upper level is a booster for regulating the generator field. At each end of each engine-room is the main feed tank, situated rather high up, and the direct-current switchboard. The cables from the generators pass through the engine rooms to a control room containing the main switchboard and all the control apparatus.

There are four main motors in three separate watertight compartments. The motor is of the induction type and is wound for two speeds at full frequency, there being a 24-pole and a 36-pole winding. Each motor has mounted on the top of the stator a ventilating fan for keeping the windings cool.

The main turbines are of the impulse-reaction type. Each is fitted with a specially designed hydraulic governor to regulate the steam supply. This fitting is different from that in the New Mexico; the only trouble experienced in that ship was due to the governor.

At full power the generators, which are three-phase, run at about 2,000 r.p.m., and each develops 12,000 kw. at about 3,600 volts and 35 cycles. From full power (propeller revolutions 170 per minute) down to that giving the ship a speed of about 17 knots (propeller revolutions 135 per minute), the revolutions of the generators and consequently of the motors, are reduced by reducing the steam supply; throughout this range, the motors are connected to the 24-pole winding. Below this speed only one generator is required. From 17 down to about 15 knots the motors can be connected either to the 24-pole or the 36-pole winding, and speed regulation is again obtained by regulating the steam supply. For best economy at speeds below 15 knots, the motors are connected to the 36-pole winding. At 15 knots the turbine revolutions per minute are about 1,700, so that over a wide range of speed the turbines are running at high revolutions.

Naturally the question arises:—How does this system compare with geared turbines? A thoroughly convincing answer to that question is difficult to give, for we have a battle cruiser with geared turbines, but no battleships; while the Americans have on service battleships electrically propelled, but no battle cruisers. A comparison between vessels of the same class is not possible, but data have been published concerning the New Mexico, and they can be compared with those from our Hood. When making this comparison, as a constructor, I naturally ask first:—Does electric propulsion result in economy in weight? And the answer is "No." The Hood's machinery develops 2¼ times more shaft horse-power per ton than that of the New Mexico or the Tennessee. The second query is:—Does electric propulsion result in economy of space? Again the answer is "No." The engine-room space in Hood is such that her machinery develops three times more shaft horse-power per square foot than that of these battleships. No advocate of the system can combat these figures. The very fact that electric propulsion has not been adopted for United States light cruisers and destroyers—vessels in which economy of weight and space are of paramount importance—indicates the limitations of the system in this respect.

Now I come to the question of economy. Is the system so much more economical that, for a given radius of action, the extra weight of electric propelling machinery is more than counterbalanced by the smaller amount of fuel that has to be carried? Again the answer is "No." At full power the steam consumption for all purposes of H.M.S. Hood is about 0·5 lb. per shaft horse-power per hour less than that of U.S.S. New Mexico, at one-fifth full power about 0·2 lb. less, and at one-tenth full power about 1 lb. less. Even if the situation in regard to economy were reversed to the same degree, the argument for electric propulsion would still not be very strong, for heavy, bulky machinery must be heavily protected, while oil fuel need not be and can be stowed in spaces otherwise useless.

What advantage, then, does the system possess? One important one. Owing to the absence of mechanical connection between the shafting and the main engines it is possible to divide the vessel more minutely and provide greater safety. But, against this, the advocates of the geared turbine maintain that, under shell fire, the electric machinery is much more likely to suffer, and I must confess that, when I looked at the bare 'bus-bars and the large open ventilating trunks for motors and generators in the New Mexico, I conceded that point.

On the score of reliability, ease of operation and repair, it is for the electrical and steam engineer to speak rather than for me. Both maintain that with either system:—"When everything goes all right, there is nothing to do, and if anything goes wrong—well, you can't do anything." Why, then, have the Americans adopted this system? In reply, I make this suggestion. When all engineers were looking for a solution to the problem of how to combine a fast-running economical turbine with a slow-running economical propeller, national traits became evident. I believe our marine and mechanical engineers always have been, and still are, second to none in turbine design and gear cutting; they have perfected gearing and the turbine with its elements for economic performance at cruising speeds. On the other hand, electrical engineering science has been more highly developed in the United States, and electric propulsion is consequently more suited to the American temperament. Moreover, the situation of the United States and her possessions is such that American naval authorities attach great importance to radius of action. At the time they decided in favour of electric propulsion, this system showed promise of such high economy, compared with the direct-turbine drive, that for this reason alone they were willing to adopt it; probably they did not foresee the possibility of similar economy through the adoption of mechanical gearing and improvements in turbines.

I may be told that I have been unfair and should consider the promised performance of the United States battle cruisers. My answer is—I am dealing with accomplished facts. These battle cruisers do not exist. If they did exist, the comparison with our battle cruisers, which share the same scrap heap, would, I am sure, lead to the same conclusion. Anyhow, the figures I have given are sufficiently striking to justify a general deduction.

The Maryland, Washington and Colorado, of the class following the Tennessee, will be the last capital ships added to the United States Navy during the next ten years. They have practically the same dimensions as the Tennessee, and differ only in the main armament, which consists of eight 16-in. 45-calibre guns in four turrets.

Although the battleships of the "North Carolina" class are to be scrapped, they are of interest as indicating the latest American ideas and practice. I became thoroughly acquainted with these designs when serving in the Bureau of Construction and Repair during the war, and, as far as I know, few modifications have been made since, but it is possible that the information I am giving is not absolutely up-to-date. Figs. 7, 8 and 9 show the general arrangement of these vessels, of which the following are the leading particulars:—

Length on water line	660 ft.
Breadth	105 ft.
Draught	33 ft.
Displacement	43,200 tons.
Armament	Twelve 16-in. 50-calibre guns. Sixteen 6-in. Four 3-in. H.A. Two 21-in. torpedo tubes.
Machinery	12 oil-fired boilers in 12 boiler rooms. Two turbo-generators driving four motors. Shaft horse-power, 60,000. Speed, 23 knots.

The main armament is the most striking feature of these vessels. The gun itself weighs about 140 tons and the turret complete about 1,400 tons. It is easy to imagine how difficult is the problem of efficient support for such an enormous revolving weight. The gun fires a shell of 2,100 lb., with a muzzle velocity of 2,800 ft.-seconds, for which a full charge weighing about 720 lb. is required. It will be seen from the drawings that the volume of propellant for 12 such guns involves a very large space for the main magazines.

The general arrangement of the machinery is similar to that of the Tennessee, and the illustrations clearly indicate how electric propulsion has assisted in the adoption of close watertight subdivision. The quadruple ends by shells is obviously accepted as a possibility which need not be feared as likely to put the ship out of action. Before and abaft the citadel is a heavy deck below the water line. This protects the torpedo rooms forward and the steering gear aft, and guards against loss of buoyancy and excessive trim by the bow or stern which might follow from damage to the ends by shell fire at long range.

The armour of the barbettes is as thick as the main belt, and the front plate of the gun shield is still thicker probably on account of its slope, which is such that normal impact is likely. The turret roofs are 5 in. in thickness, and may be more, as I have heard many United States officers express the opinion that nothing conclusion that protection which is considered adequate to meet the attack of a 2,000-lb. shell descending at a steep angle should be adequate against the bombs which can at present be carried and which would have a smaller striking velocity. It should further be noticed that if the bomb explodes, as is likely, before it reaches the armoured deck, the damage would certainly be more spectacular than effective. I think it will be agreed that, until some new development in projectiles is forthcoming, this system of protection is thoroughly sound.

The under-water protection of this ship, which is shown in Fig. 16, is similar to that of the Tennessee. It consists of a system of longitudinal and transverse bulkheads, the former being closely spaced about 3 ft.

Fig. 7. ELEVATION. *ARRANGEMENT OF COMPARTMENTS.*

Fig. 8. PLAN OF LOWER DECK.

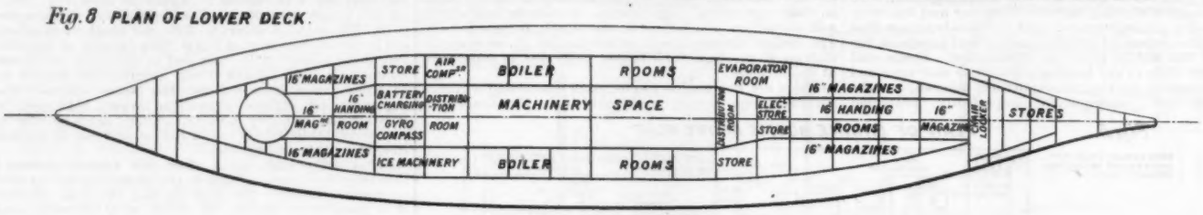


Fig. 9. PLAN OF PLATFORM DECK.

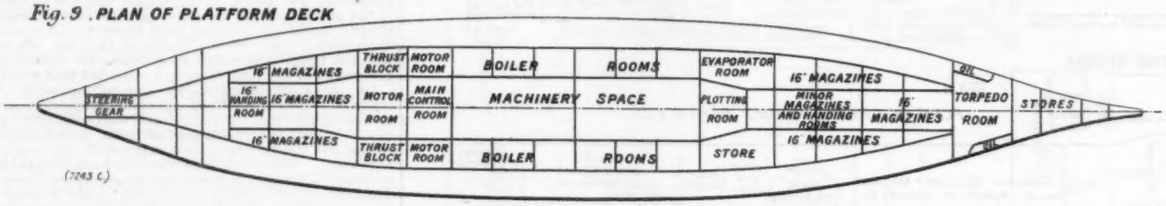


Fig. 10. PROTECTION AGAINST GUN AND BOMB ATTACK.

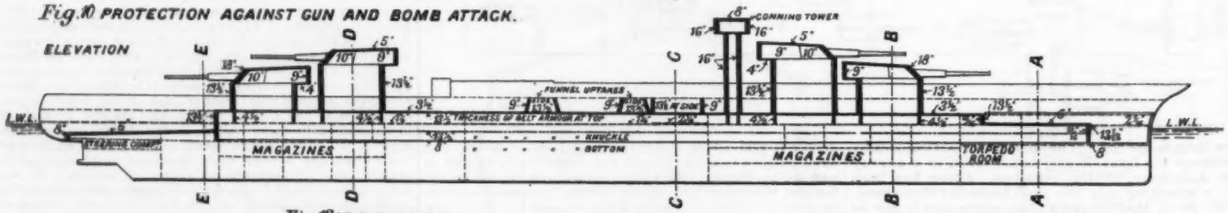


Fig. 11. SECTION AT E.E.

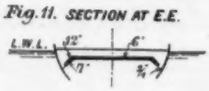


Fig. 12. SECTION AT D.D.

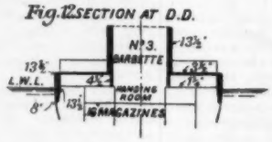


Fig. 13. SECTION AT C.C.

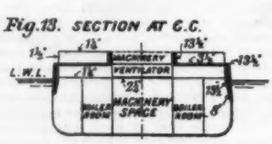


Fig. 14. SECTION AT B.B.

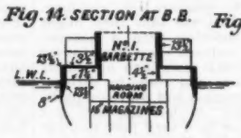


Fig. 15. SECTION AT A.A.

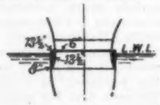
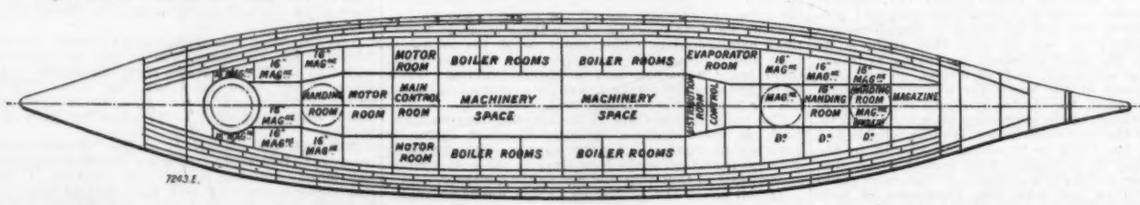


Fig. 16. UNDER-WATER PROTECTION.



funnel proposed for these vessels has already provoked remarks, but it is easy to see that, with the arrangement of boiler and engine rooms and the protection described later, it is much more desirable to join the uptakes above the weather deck rather than below. Incidentally, the smoke is then emitted some distance away from the bridge and controls, and the shape of the funnel itself makes the vessel a poor mark for a range-taker.

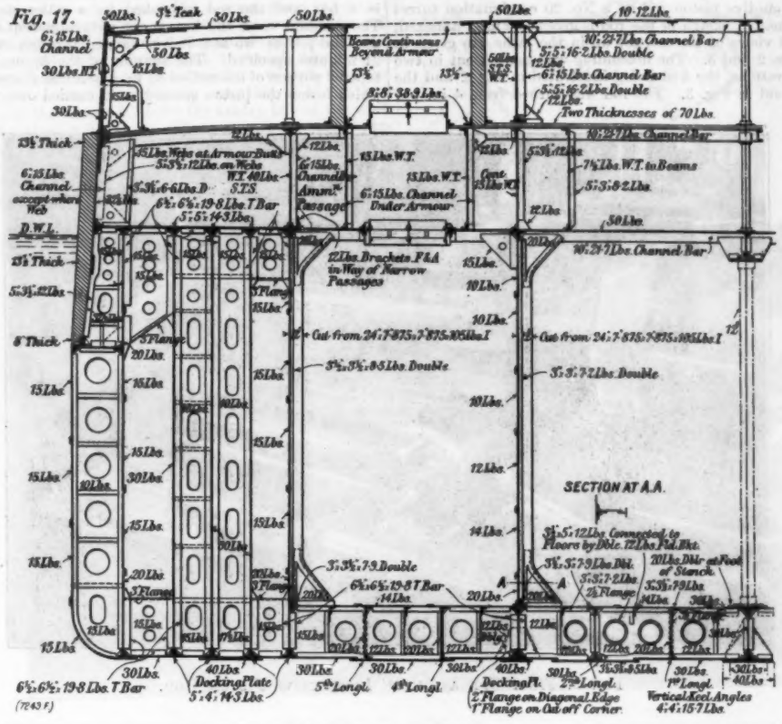
Protection against gun and bomb attack is shown in Figs. 10 to 15. It is evident from an examination of these illustrations that the opinion held by the designer is that the armour-piercing shell which is able to beat the belt or deck and explode behind is the type of projectile to be feared most; hence the thick belt over the vitals with a heavy deck above it forming, with the heavy transverse bulkheads, a box which it is hoped is invulnerable. Below the heavy deck is a moderately thick deck to hold up shell splinters or fragments detached from the main deck. Light armour, to keep out shells containing large bursting charges, is conspicuously absent: the wrecking of the topsides and unprotected less than 8 in. was sufficient. The conning tower is of the spindle type and is shaped like a lozenge, with the greater dimension athwartships, so that it is more likely to receive a glancing blow.

A particularly interesting feature is the armour round the funnel uptakes and the trunk supplying air to boiler and engine rooms. The former is a feature of most modern United States battleships, and it was originally adopted to prevent a ship from being severely handicapped by smoke from damaged uptakes escaping on to the living decks. It is obvious that a stronger reason for such protection now exists. The heavy deck might be useless under long range attack if the large holes for such purposes were not protected in some such manner; a lucky shell might find this hole and burst well below the armoured deck. It would be just possible for this to happen at the air supply trunk, but the supply shaft is not vertically below the armour and the deck at the bottom is thickened up to guard against this eventuality.

The illustration is entitled "Protection against Bomb Attack," because a little consideration should lead to the apart and the latter staggered so that damage to one will not extend right into the inmost longitudinal bulkhead. The outer and inner of the five wing compartments are air spaces, and the three central compartments are oil fuel tanks. All the compartments are severely tested before acceptance, the pressure head for water test being 44 ft. Inside these bulkheads the main hull is well subdivided both longitudinally and transversely. This arrangement was adopted after an extensive series of trials on a large scale. It is evidently based on the principle of keeping the centre of disturbance a considerable distance from the bulkheads bounding important compartments and absorbing the energy by the progressive rupture of bulkheads and the compression of fluid.

This system is very economical in weight, but, in my opinion, it possesses several weak features. In the first place, the work and time involved in building are very considerable. Secondly, it is just possible that a torpedo may find the weak spot where the oil tanks are empty. The answer to this criticism is that these

AMERICAN WARSHIP PRACTICE.



side tanks are those to be emptied last, and even if oil has been taken from them they can be filled with sea water. My reply is that human nature must be taken into account and filling oil fuel tanks with salt water gives trouble which an engineer officer would be tempted to shirk. Again the various fittings to these tanks, suctions, &c., involve perforations in the bulkheads and impair watertightness, and our experience during the war was that such fittings were the cause of an extension of flooding beyond that actually caused by the damage. What I consider to be the most serious objection is that the effect of an explosion would be to open the middle deck to the sea with consequent loss of stability.

The structural features of the design are shown in Fig. 17. After examining this figure those familiar with warship construction will realise at once that, for a ship of this size, scantlings have been cut to the bone. The framing is on the usual system for warships—a combination of the transverse and longitudinal systems. The lightened plate type of frame is that generally followed, the lightening holes, in certain cases, being flanged. The main bulkhead stiffeners are very carefully designed. They are formed from a cut I-bar with double angles, the section being split at top and bottom and opened out to form the brackets.

The armour is worked vertically and keyed at the butts; hence the outstanding belt. This is an excellent feature, as was proved by our experience with H.M.S. Lion in the Dogger Bank action. The heavy deck is worked in two thicknesses, one strake forms the butt strap of the other, but in order to develop the strength of the total thickness, each plate is machined to a tapered scarph at the butt and rivets are fitted through the three thicknesses. The lower strake of this plating is nickel steel and the upper strake is what is termed "special treatment steel." This is a nickel chrome steel, which has received some comparatively inexpensive heat treatment; it is consequently nothing like as costly as armour, but possesses ballistic properties approaching those of armour.

(To be continued.)

THE IMPROVEMENT OF THE PORT OF VALPARAISO.*

By ARTHUR CLIFFE WALSH and WILLIAM FRANK STANTON, B.Sc.(Eng.), Assoc.MM.Inst.C.E.

THE authors' intention has been to pass quickly over the stereotyped part of this work, and to devote their description to the more unusual features. Since its foundation, Valparaiso has been the principal port of the West Coast of South America, but until the old Fiscal Mole was completed in 1883, it had no accommodation for shipping. The bay faces north, and is protected from the ruling southerly wind, but is exposed to occasional winter gales from the north. In 1912 the Chilean Government signed a contract with the firm of S. Pearson and Son, Limited, for the improvement of the port for the sum of about 2,500,000*l*. The contractors opened up a quarry at Las Salinas on the eastern side of the bay, where they also established their work yards and built a loading jetty. Both timber and concrete piles were used in the construction of the jetty, and, in spite of attempts at protection, the former were soon seriously weakened by the teredo. The piles were restored without interruption to traffic by surrounding with small iron cylinders which were filled with fine crushed stone and grouted up with cement. Special cranes for loading 2,000 tons of rubble per day into hopper barges, and a 60-ton Titan for blocks, were installed on the jetty; all these cranes were electric. Near-by was a block-making yard with electric travelling mixers, which had a capacity of 5,000 cub. m. per month. Between this yard and the quarry was situated the stone-crushing plant. Workshops and a power plant of 500 kw. capacity completed the equipment at Las Salinas.

The difficulty in protecting the bay lies in its great depth and the unstable nature of the bottom. Experiments were made to determine the settlement to be anticipated under the weight of the proposed breakwater, as a result of which a blockwork structure was considered sufficient for the first 536 ft., but a design of large monoliths was considered more appropriate for the outer 390 ft. The blockwork section was founded on a rubble bank tipped from hoppers to 16 ft. below mean sea level. The blocks were set by a floating crane, and were surmounted by mass concrete and a parapet. Six monoliths were placed at the outer end of the breakwater, each weighing some 12,000 tons. The greatest depth of water reached is 148 ft. The monolith shells were built of reinforced concrete, and were specially designed to withstand the stresses likely to arise in standing through winter with a temporary filling of sand. However, as the settlement after filling the first monolith did not exceed 2 ft., it was decided to place the permanent concrete filling in the remainder without waiting for the temporary weighting period. The actual settlement experienced did not differ greatly from those anticipated from experiment.

After considering many schemes it was decided to build the monoliths in a temporary dock formed of steel pile cofferdams built behind the old Fiscal Mole. A 24-in. centrifugal pump had to be used to lower the water in this dock, but once the steel piling was caulked, a 6-in. pump could easily keep it dry. Light Goliath cranes spanning the dock were used to handle concrete and shuttering. The monoliths drew 25 ft. of water when undocked and were ballasted down to 39 ft. before setting. The first monolith had to be set as an island: it was moored in position between the floating crane and a hopper barge, and sunk by admitting water through valves provided for the purpose. By pumping out the compartments in turn the concrete filling was placed in the dry. The remaining monoliths were placed with the help of timber walings overlapping the monolith last set. These walings were secured by heavy springs which absorbed the blows received from the monolith. The monolith being set was held up to the preceding one by means of blocks and tackles. The joints between the monoliths were small, but in settling, one of them opened up to 18 inches; this was filled with concrete placed by a small bottom dumping skip.

The quay walls were built of 60-ton blocks on a rubble base. The Customs quay, 2,067 ft. long, was built by a 60-ton travelling derrick. The Fiscal Mole, 1,214 ft. long, and the Prat Quay, 689 ft. long, were built by the floating crane. The draught alongside all the walls is 39 ft., and the quay level is 13 ft. above mean sea level. The walls of the mooring jetty have not yet been built. The depth of water on this site reached over 100 ft., and, in tipping the bank of quarry rubbish and rubble which forms the foundation for the walls, large settlements took place, and the finished bank is now under observation to decide what type of superstructure to adopt.

For the coal traffic a reinforced concrete pier was built, 750 ft. long and 98 ft. wide, carried on cylinders also of reinforced concrete. Most of the concrete was built in sections in the yard at Salinas, and assembled with special cranes. A staging was built for sinking the cylinders, which were lowered into place by an arrangement of hydraulic jacks, and sunk by grabbing. Piles were driven inside the cylinders. The mole is equipped with the necessary railways and a granolithic pavement.

The harbour front for 2,445 ft. east of the mooring jetty is built of monolith blocks founded on large rubble at a depth of 26 ft. Each monolith is 33 ft. long, 23 ft. wide at the base, and 31 ft. high. A small mass concrete superstructure brings the wall up to the quay level, 13 ft. above mean low water. The reinforced concrete shells were built on the reclamation behind the new quay wall, and lowered into the water by means of a carriage and lift operated hydraulically. The lift platform was carried by large plate girders with one end resting on the quay and the other on dolphins of timber piles. The concrete and shuttering were handled by two 5-ton cranes, and the capacity of the yard was three shells per month. The monoliths were set by means similar to those described at the breakwater, and sunk into their beds by placing a 60-ton block with the floating crane. Most of the joints were close, and none exceeded 8 in.; the few which were 5 in. wide or over were stopped by means of a concrete pile.

The reclamation to the west of the sea-wall just described was continued for a distance of 5,446 ft. by means of a rubble slope. This bank was built end on by a 16-ton derrick crane which could tip over 600 tons of rubble per day. The filling, where possible, was carried out by a suction dredger.

The Minister of Finance, advised by a Port Commission, controlled the work of the Government. For the contractors, Sir Edward E. Pearson was the London director, and Mr. Arthur C. Walsh was in charge in Valparaiso, with Mr. W. F. Stanton as chief engineer, during the whole seven years of the contract.

* Abstract of a paper read before the Institution of Civil Engineers, on Tuesday, March 7, 1922.

THE INSTITUTION OF ELECTRICAL ENGINEERS.—A permanent wireless aerial has been installed on the I.E.E. building for reception purposes. The details are as follows: Span between strain insulators, 113 ft.; down-lead from aerial to leading-in insulator (outside), 63 ft.; down-lead from leading-in insulator to floor of lecture theatre, 44 ft.; total down-lead, 107 ft. Effective length of aerial: Down-lead plus half span, 163·5 ft.; natural wave-length (approximately), 200 m.

AMALGAMATION OF SPANISH AND GERMAN INTERESTS.—The amalgamation of the Spanish company, Aceros Electro Rapidos, of San Sebastian, with a German (Cologne) combine, has been reported from a local source to H.M. Consul-General at Barcelona, says *The Board of Trade Journal*. The Spanish company owns metallurgical and machinery works, while the German group is engaged in railway wagon and material construction. The Spanish firm is stated to have secured contracts with the two largest railway companies in Spain for the repair of 200 wagons per month.

VESSELS LOST, CONDEMNED, &C.—According to statistics recently issued by Lloyd's Register, the number of vessels lost, condemned or removed from the Register from other causes, during the quarter ended September 30, 1921, was 107, and the total gross tonnage amounted to 141,581, these figures including 65 steamers making 119,662 tons and 42 sailing ships making 21,919 tons. The heaviest tonnage loss was suffered by the United States, the figure for that country being 31,502, comprised in 16 vessels; the tonnage, however, amounts to only 0·21 per cent. of the total owned in the United States. The British losses during the quarter were lower both proportionally and actually, the tonnage lost by this country, viz., 24,192, representing 0·12 of the total tonnage owned in the United Kingdom; the number of British ships removed from the Register was 15. Comparatively, the losses of the British Dominions were greater than those of the Mother Country, the figures being 22 ships making 19,884 tons and the tonnage amounting to 0·79 per cent. of the total owned by the Dominions collectively. The Japanese ships lost during the period numbered 7 and had a total tonnage of 16,434, which is 0·49 per cent. of the total, and the corresponding figures for Italy, Spain and France are: 9 ships, 10,767 tons (0·41 per cent.); 5 ships, 8,858 tons (0·76 per cent.); and 13 ships, 7,771 tons (0·21 per cent.). The only other country with losses exceeding 5,000 tons was Norway, the figures for that country being 5 ships making 7,027 tons, which is 0·27 per cent. of the total Norwegian tonnage, but a single vessel of 5,758 tons, to which no flag had been allotted, was wrecked. The above figures, it may be mentioned, include all losses reported up to February 4 of this year as having occurred during the quarter under consideration.

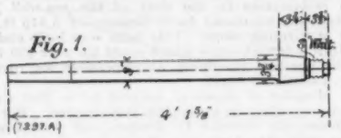
MACHINE TOOL PROGRESS.

PROGRESS in any modern machine shop is continuous. New parts to machine suggest new methods of machining, and these in turn suggest better methods of carrying out older tasks. Improvements in steels and experience with new steels lead to new forms of tool and new ways of tackling various jobs. Progress which depends on developments of this kind is of great importance in improving quality and cutting down machining times, and is to a considerable extent independent from important capital expenditure on new machine tools.

This particular form of progress is, as we have said, to be found in any modern machine shop, but naturally is likely to be found in its most advanced form in shops, the chief interest of which is concerned with machining methods rather than the production of some article, such as a motor car engine, which has in itself no direct relation to machine tool work. These reflections are suggested by a visit which we paid on the 9th inst. to the work of Messrs. Alfred Herbert Limited, at Coventry. That Messrs. Alfred Herbert have built up a leading position in machine tool practice in this country there can be no question, and it was of great interest to see a definite demonstration of a large number of the machining methods and machining appliances which they have developed over recent years.

The visit was not in any way confined to new machining methods and new machining appliances as distinct from new machine tools, but it was these former aspects of the demonstration which chiefly impressed us. The whole of the material and methods shown were not new in the sense that they were novelties, and many of them have been dealt with in our columns in the past. They were all, however, developments of the last few years and collected together as they were for demonstration purposes they certainly illustrated in a very clear way the ability and enterprise which are keeping Messrs. Alfred Herbert in the front rank. In a sense the demonstration may be said to have been of a somewhat desultory nature, since the several appliances and various machining jobs which were exhibited had no immediate and direct relation to each other. This, however, was an inevitable feature of the scheme of the display and detracted in no way from its interest. It none the less renders any preparation of an account of the demonstration rather more difficult, since space will not permit of dealing with the various items in any considerable detail; and yet at the same time it is the details of say a capstan machine tool lay out which are of interest.

Fig. 1.



In these circumstances we propose to select only some of the more striking methods and appliances for mention, and may first refer to a self-contained tool adjusting slide which was shown in use on Messrs. Herbert's No. 5 automatic. This machine was shown at the Machine Tool Exhibition of 1920, and was illustrated and described in our issue of September 10 of that year, and we need not deal with it here. It will be of interest to mention, however, that an extra steady has been recently added to the machine. This consists of an horizontal bar projecting from the top of the headstock and entering a guide, carried by the turret, as the turret moves forward. The arrangement adds considerable extra stiffness to the machine when a heavy or irregular cut is being taken. The device is, of course, not new and is practically an application of the usual method of supporting the front end of a tool bar in a bush mounted in the spindle. This addition to Messrs. Herbert's No. 5 automatic turret lathe interested us considerably, however, as we think even yet there is insufficient general appreciation of the importance of stiffness and good support in heavy and rapid machining operations. The ordinary back steady dates at least from the days of the first lathes which could be described as machine tools, and yet the obvious lesson that it conveys does not yet seem to have been appreciated by many builders of capstans and other modern machine tools. We commenced this paragraph by referring to a self-contained tool adjusting slide which was shown in operation on the No. 5 automatic. This consists of a screw operated tool holder working over a fixed slide. The whole arrangement is self-contained and is mounted on the turret as required for the job in hand. The advantage of the arrangement is that a fine and easily operated adjustment is made available for the tool during setting up and also subsequently in case of wear. The arrangement should be specially valuable for roughing operations with semi-skilled labour, and for more finished work in the hands of a skilled man.

The next piece of work to which we may refer was the machining of a Lancashire and Yorkshire Railway locomotive piston rod on a No. 20 combination turret lathe. A sketch of the rod is given in Fig. 1 annexed, and views of the rod set up in the lathe are given in Figs. 2 and 3. The machining was carried out in two operations, the first being illustrated in Fig. 2 and the second in Fig. 3. The rod was turned from 4 in. bar and the total machining time was 30 minutes, the first operation occupying 21 minutes and the second 9 minutes. The two operations were, of course, carried out on different machines, and the times given above are not floor to floor times and make no allowances for the time consumed in removing the rod from one machine to the other. They also cover only the rough machining of the parallel part of the rod which is afterwards finished by grinding. It will none the less be realised that these machining times constitute a remarkable performance.

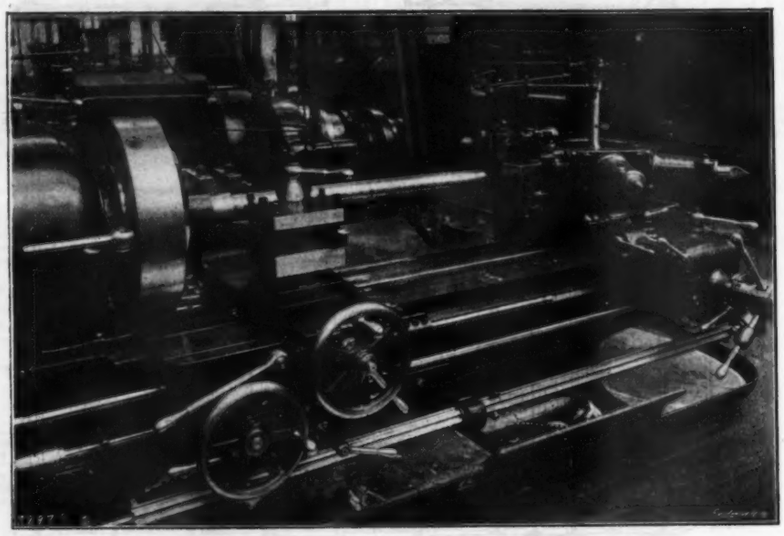


FIG. 2. FIRST OPERATION ON LOCOMOTIVE PISTON ROD.

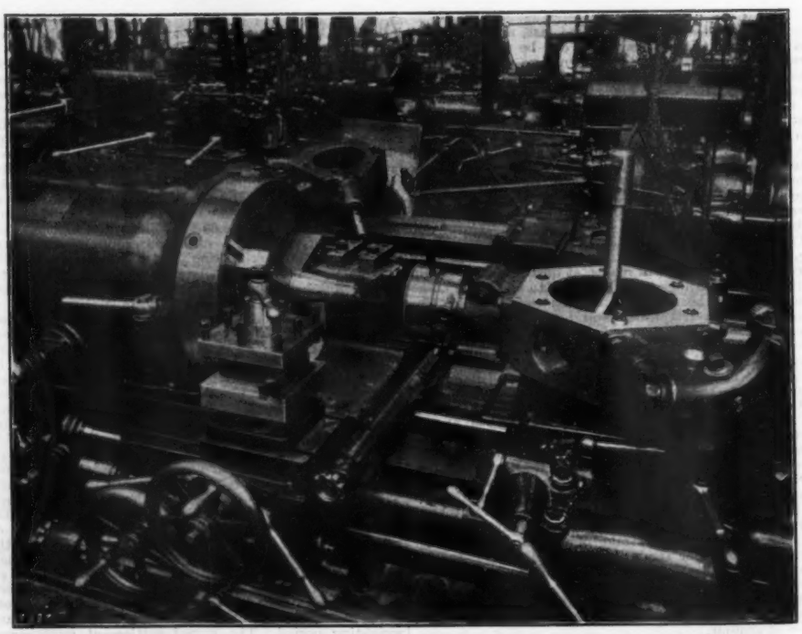


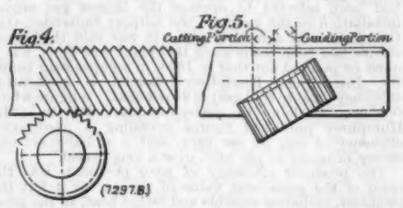
FIG. 3. SECOND OPERATION ON LOCOMOTIVE PISTON ROD.

The rod is turned from black bar, and is held in specially shallow chuck jaws so that the shape of the bar where it is gripped shall not exercise too much control over the far end. The rod is centred from the turret and is then turned down a short distance at the end to give a fair lead to the main tool which reduces it to 3 in. diameter in a single cut. The tool is carried in a box and the rod is backed by a roller steady. The machine took the heavy cut with apparent ease, and the job as we saw it was carried through in the 21 minutes specified. The shaping of the 3¾ in. long tapered portion of the rod, of 3¾ in. maximum diameter, which forms the piston seating, was carried out with form tools from the cross-slide while the turning of the main body was in progress. This slide was not advanced until the turret tool had travelled forward on to the rod so that its free end was well supported. The final cut of the first operation formed the taper on the free end. This was carried out from another face of the turret. The second operation, consisting of the turning down and screwing of the other end of the rod in a second machine is adequately illustrated in Fig. 3 and need not be referred to in detail.

The next item to which we would refer is illustrated in Figs. 4 to 7 opposite. This is a quite novel method of cutting multi-threads or producing knurling. The device which is used has been called a " multi-

chaser" by Messrs. Herbert. It somewhat resembles a Fellows' gear cutter and is shown in operation in Figs. 6 and 7, while diagrammatic drawings of it are given in Figs. 4 and 5. The chaser is mounted in a forked holder in such a way that it can rotate so that it operates to some extent like a worm wheel in contact with the work, which represents the worm. As will be seen from Figs. 6 and 7, the multi-chaser is set over at an angle from the vertical, the angle being equal to the helix angle of the thread to be cut. As can further be seen from Fig. 5, a portion of the cutting face of the chaser is above the centre line of the work and a portion is below. The portion below the centre cuts, and the portion above acts as a guide. The chaser is driven by the work and rotates in mesh with it, and when a slow traverse is put on, the threads can be cut in one pass. There is a thread-cutting system in existence which employs a cutter somewhat of the form of the multi-chaser, but in that case the cutter is driven through gearing. The multi-chaser, on the contrary, is driven by the work.

We believe this tool has not as yet had any application to production work in connection with thread cutting, although there would appear to be possibilities in it of important development. It has, however, been used for knurling feed rollers for the linoleum trade. The advantage of the multi-chaser over the ordinary knurling tool is that it is a true cutting tool. A knurling tool, on the other hand, deforms the surface with which it is dealing rather than cuts it. In coarse knurling it is very difficult to produce sharp points to the pyramids formed, and in any case very great pressure is required to do the work at all. The linoleum rollers to which we have referred consist of tubes with comparatively thin walls, and would be destroyed by any attempt made to produce the effect given by the multi-chaser with a knurling tool. Another example of which Messrs. Herbert have experience is in connection with the knurling of large studs, which have to be roughened preparatory to being covered with insulating material. The knurling of these in the ordinary way was a heavy job, occupying about 1¼ hours, while a knurling tool proved capable of dealing with only one or two studs before it was destroyed. With the multi-chaser the job was completed in four minutes. The illustrations given in Figs. 6 and 7 show the tool engaged in a knurling operation. The tool is of course traversed first in one direction and then in the other.



Our remaining two illustrations, Figs. 8 and 9, show a new form of universal vice fitted to a bench surface grinder. This is a small but handy piece of apparatus, which should prove valuable in the tool room for all sorts of small form-cutter work. The vice is also suitable for the grinding of Landis chasers. The details of the appliance will be fairly well understood from the figures. As will be seen, the two pivots at right angles give adjustment in two planes, while slewing in the third plane may be obtained by setting the vice round on its base. The chaser, or cutter, is held by a small jaw pulled forward by an internal screw in the upper pivot and controlled by the milled head, which can be seen in the figures. Traverse across the grinding wheel is obtained by operating the table of the bench grinder on which the vice is mounted.

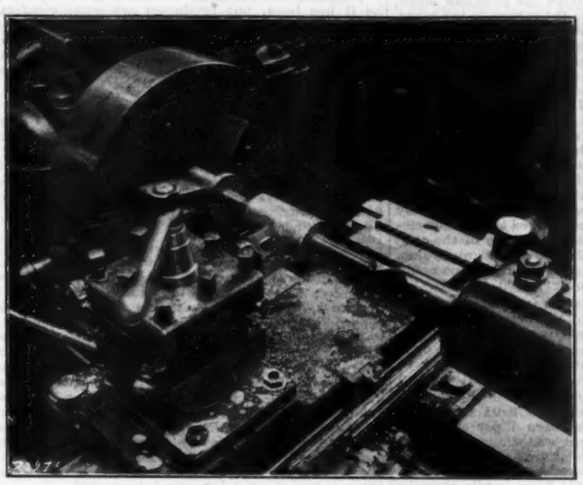


FIG. 6.

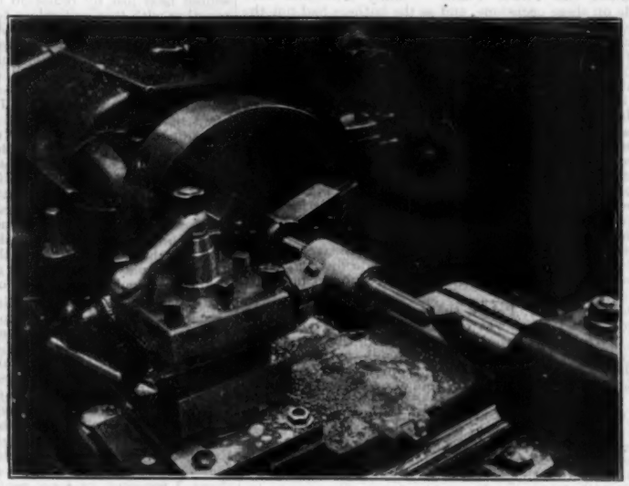


FIG. 7.

FIGS. 4 TO 7. "MULTI-CHASER" FOR THREAD-CUTTING AND KNURLING.

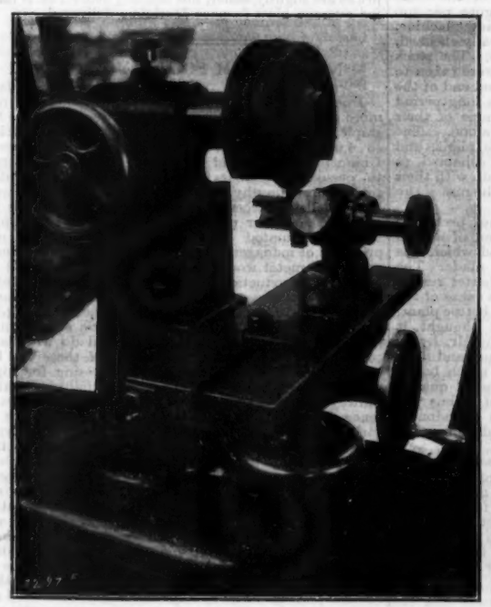


FIG. 8.

FIG. 9.

FIGS. 8 AND 9. UNIVERSAL VICE FOR BENCH GRINDER.

Another new device, or set of devices, recently introduced by Messrs. Herbert, and which was shown in operation, takes the form of a speeder and de-speeder for drills, a new tapping attachment, and a new stud driver. The drill speeder steps up the speed of a drilling machine spindle by some five times, so that a sensitive drill having a top speed of 2,000 revolutions per minute may be stepped up to a speed of 10,000, the lower speeds, of course, being stepped up in proportion. The speeder is self-contained, light, and fits the taper of the drilling machine socket. It enables very small drills to be utilised on a sensitive machine efficiently and without danger of breaking. The arrangement should be particularly useful in connection with the somewhat miscellaneous collection of holes which have at times to be drilled in a single piece on a radial drilling machine. A machine capable of tackling quite large holes may with the speeder at once be made suitable for drilling small oil holes. The de-speeder is the speeder reversed. It enables large holes to be drilled on small machines. Its chief value will probably be found to be in its suitability for garages and repair shops, in which the total work done will not justify a heavy drilling machine, but in which it is necessary at times to tackle a heavier piece of drilling than is usual.

The tapping attachment we need not refer to in detail. It follows well-known lines and is a re-design in a very neat form of the tapper which Messrs. Herberts' have previously manufactured. The studding attachment is, however, we think, quite a novelty. The stud to be driven is carried in a socket, or plunger, which is formed like a portion of a ball at its top end. This ball surface bears against a transversely movable wedge when the socket is in position in its holder. The ends of the wedge work in a circular recess in the holder, the recess being eccentric to the hole in which the socket slides. The effect of the arrangement is that, as the driver comes down and begins to screw the stud into the work, the wedge is forced round and locks itself in the recess and so gives the drive. The arrangement is fitted with a reversing arrangement like a tapper, and when the stud is driven and pressure is eased off

so that the reverse comes into operation, the holder makes a partial turn without turning the socket. This releases the wedge, and the arrangement then unscrews itself from the stud, which is left in position in the work. A spring keeps the holder in the forward driving position when at rest, and all that it is necessary to do when using the device is to screw each stud in turn a few threads into the socket, bring it down on to the work, and lift the drill spindle when the stud is fully driven.

PRODUCER GAS POWER PLANT.

IN our issues of February 3 and 10 (pages 142 and 160) we reported discussions, at Manchester and London meetings of the Institution of Mechanical Engineers, of a paper by Messrs. H. S. Denny, C.B.E., and N. V. S. Knibbs, B.Sc., entitled "Some Observations on a Producer Gas Power Plant." Many criticisms were made on these occasions, and as the authors had not the opportunity of meeting these in the time it was possible to allow them after the discussions, we give below an abstract of the more detailed reply they have communicated for publication in the proceedings. This reply combines the discussion at both meetings. The following is a summary :—

Mr. Fielden had stated that he thought the rated capacity of the producers was too high. The authors agreed, but the figure given was the maker's rating. Circumstances prevented a departure from recovery conditions. Mr. Fielden took exception to the ammonia absorption method of calculating volume. The authors were unable to follow his objections. The method presupposed no definite relationship between volume and ammonia content. If the analysis of the gas were accurate and taken on a truly representative sample, and if the total ammonia sulphate made (or acid used) were known accurately, the deduced volume must be correct.

In reply to Mr. Paton, the coal was not of a coking nature. The plant was operated under the conditions laid down by the designers for gasifying this same coal. They did not follow Mr. Paton's calculation purporting to show that the whole of the gas would be required for steam raising if no coal-fired boilers had been employed. He found the steam employed to be equivalent to 333 tons of coal, but assumed its use in boilers of 70 per cent. efficiency, whereas the actual efficiency was about 45 per cent., the same as the figure he took for gas-fired boilers. With regard to good yields of ammonia being obtained with a thin fuel bed, the coal was exceptionally good at that time, and possibly the results were to be attributed to that factor alone. Mr. Paton's figures for the Moore producer were of great interest, but it was astonishing that the issuing gas should be at as low a temperature as 200 deg. C.

Dr. Morley thought the evaporation from the exhaust boilers was higher than would be expected from the conditions of heat exchange. There was, however, good reason to believe that the recorded temperatures and mixture were substantially correct, whilst a few measurements of the boiler exit all showed temperatures of less than 400 deg. F.

They regarded the coal used as a very good coal—very much better than the slacks which were said to be gasified in recovery plants. Nevertheless a coal containing a lower percentage of fines would undoubtedly furnish better results. They had pointed out in the paper as originally written that the extra steam required was just obtainable from efficient exhaust heat boilers. There would not, however, be sufficient to operate the auxiliaries in addition. With regard to Messrs. Bone and Wheeler's results, they would point out that those figures were obtained using a coal of 13,900 B.Th.U. gross screened over 1 in. The carbon balance method could safely be applied to a test on one producer with special facilities for collecting all residues, &c., and they had no doubt that it was accurate in Professor Bone's experiments. In a week's test on a large commercial plant it was a very different matter.

In regard to the formula criticised, Mr. Hodgson stated that it was 300 per cent. in error, but he would appear to have forgotten the $\sqrt{10}$ in the denominator. The manometer used was an accurate one, and its readings had been compared with those given by a sensitive differential gauge before it was used in the tests. The pulsations were not large and the error introduced by reading the damped head was taken into consideration at the time and found to be less than the error of measurement. Mr. Hodgson advocated the use of the Stauscheibe form of Pitot tube, and they were particularly interested in his remarks because Recknagel, Müller, Rietschel and others had obtained rather varying results with this, which fact seemed to render its use uncertain. Doubtless a standard calibrated instrument would be accurate. The authors thought the Venturi tube was unsuitable for a producer gas carrying tar and soot, but for cold gas containing only light tar it would be quite suitable.

Mr. Lymn had enlarged upon the age of the plant, maintaining that its obsolescence made the figures valueless. It was, as he said, designed in 1907, but was not completed and put into operation until 1909, and was therefore only nine years old, and not fifteen, at the time the tests were made (1918). The fact that a large power plant and very costly chemical factory were erected in 1916-17 to be operated entirely by this producer plant scarcely suggests that it was then regarded as obsolete. It is true that the plant was built primarily to produce ammonium sulphate, but it was not clear in what respect it differed from any other Mond plant erected about the same time, nor was the pre-war cost of over 60,000*l.* coupled with the recovery of only 76 lb. of sulphate, when operated solely for the recovery of the latter, eloquent of the designer's success in keeping down capital cost without sacrificing sulphate recovery.

Mr. Lymn had said it was strange that a plant built purely as a chemical factory should be chosen for a paper on thermal efficiency, but as that "chemical factory" had been selected to operate the largest gas engine installation in the country, the authors contended that the choice was a natural one. It was said that great strides had been made since this plant was built, but it must be pointed out that in 1900, in a paper read before the Institution, Humphrey claimed a gasification efficiency (coal to cold gas) of 84 per cent. ; a figure which few would claim to better to-day. But in 1912, Humphrey published figures revealing a gasification efficiency of only 58 per cent. and a probable net efficiency of under 40 per cent. over a long period.

The producer efficiency of 80·9 per cent. was the ratio of the gross heat value of the gas as it left the producer, including sensible and latent heat, to the gross heat entering it, and the 19·1 per cent. difference represented heat lost by radiation from the producer alone, together with that equivalent to the carbon in the ashes, dust and tar. The plant was admittedly leaking in the latter part of 1918, but it was difficult to see in what other respect conditions were antagonistic as the makers' conditions as to air saturation, &c., were closely adhered to.

The figures given by Mr. Lymn for an up-to-date plant, if they were maintained over a period by a large plant, marked the beginning of a new era in coal gasification, and the recovery of 100 lb. of ammonium sulphate and 24 gallons of low-temperature tar, together with a rich gas, might well be the despair of the supporters of low-temperature carbonisation, but such figures would need to be backed up by a full investigation carried out by some standardised method. They agreed that efficiencies should be quoted on the net thermal value of the coal, and they had explained why they used the gross value. From the analysis which they gave the net value could easily be calculated. It was over 12,000 B.Th.U.

Mr. Nielsen thought the radiation from the producers accounted for 18·5 per cent. of the heat loss, but the figure included that represented by the heat value of the tar, dust, ashes, &c. The boilers were in the open air, but were well insulated and were not blowing at the joints. The main troubles were due to their bad lay-out, particularly in respect of the flue arrangements.

The manometer read correctly to 0·01 in., using verniers, and since that was between 1 per cent. and 2 per cent. of the total reading it was sufficiently close. Under the conditions in which it was employed they considered the Pitot method accurate only to within about 3 per cent. or 4 per cent. They hardly thought that a producer plant should be considered as "scrap" after eight years. If such were the case the amortisation figure alone would be about 8,000*l.* per annum, or, say, 4*s.* per ton of coal gasified, even when operating 24 hours per day—more than the pre-war value of the coal. For a day load only the amortisation figure per ton would be 8*s.* or more. The Avery weighing machine, over which all the coal passed, was periodically checked, and it was never found to be inaccurate. The stock in the bunkers was large, but precautions were taken to see that it was the same at the beginning and end of the test week. In any case the record over a long period agreed with that of the one week, and none of their conclusions was based on the week's test alone. The Lancashire boilers were part of the whole plant, and although they would have been rather ashamed to mention them if they had had anything to do with their lay-out, it was necessary to test them with the rest of the plant.

The main criticism levelled at the figures presented was that they were based on the operation of an old plant which was now quite out of date and which was out of repair at the time the tests were made. The authors had not the slightest doubt that better results were obtainable, and if their paper were the cause of the publication of another giving full data on a better plant, it would be more than justified. They thought it probable that the striking results claimed by Mr. Lymn were obtained using large nuts free from dust and fines and unquestionably it was possible to do much better with such coal. Unfortunately, if such a good quality coal was to be employed, one of the chief claims put forward for Mond gas would have to be abandoned, namely, that low-grade fuel was suitable and economical to use.

With regard to the suggested standardisation of the method of testing producers, they would suggest that the best method of measuring the volume of gas in most instances would be to measure the air used for blowing ; using some type of orifice meter on the inlet side of the blowing fan. The volume of gas was then given by a comparison of its nitrogen content with that of air. An allowance would have to be made for gas losses, but that would in most cases be small.

MOTOR LIFEBOAT FOR BRIXHAM.—A new motor lifeboat, the "Alfred and Clara Heath," has just been completed by the Royal National Lifeboat Institution for its station at Brixham, Devon. She is a self-righting lifeboat, 40 ft. by 10 ft. 6 in., is fitted with a Tylor engine developing 45 h.p., and is capable of a speed of 7½ knots. She has been built out of a legacy generously left to the Institution by the late Mr. Alfred John Heath, Putney. Her builders are Messrs. J. Samuel White, Cowes. She is the first of five sister boats of which the other four are all nearing completion. The stations for which they are being built are Selsey (Sussex), Appledore (Devon), Bembridge (Isle of Wight) and Sennen Cove (Land's End). The Institution has now 32 motor lifeboats in its fleet of 241 boats.

NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

MIDDLESBROUGH, Wednesday.

The Cleveland Iron Trade.—Labour troubles have checked business just when home demand for Cleveland pig-iron was improving, and foreign trade showed indication of expansion. The engineering crisis is viewed with no small amount of apprehension and, of course, a continuance of the stoppage of work will have its inevitable effect on the iron trade. Mottled and white qualities of iron are somewhat less scarce, and are firmer in price. All other descriptions of Cleveland pig-iron are none too plentiful, and values are well maintained. Both for home purposes and for despatch to foreign destinations, No. 1 and siliceous iron stand at 95*s.* ; No. 3 G.M.B. is 90*s.* ; No. 4 foundry, 87*s.* 6*d.* ; No. 4 forge, 82*s.* 6*d.* ; and mottled and white are 75*s.* to 80*s.*

Hematite.—Demand for hematite is hardly so good as it has been, but producers are quite comfortably placed, having fully disposed of their make over the next few weeks, so that it is difficult to purchase for delivery before the latter part of April. Nos. 1, 2 and 3 continue firm at 100*s.* f.o.t. and f.o.b., and No. 1 is at a premium of 1*s.*

Production of Pig-Iron.—Owing to continued unremunerative quotations a blast furnace on Cleveland pig-iron at the Lackenby Ironworks is being damped down. On the other hand, Messrs. Samuelson have this week rekindled a second hematite furnace at their Newport Works. This makes the number of furnaces in operation on the North-East Coast 29, of which 6 are producing Cleveland pig-iron, 14 hematite and 9 special kinds of iron.

Manufactured Iron and Steel.—In finished iron and steel there is absence of new development of moment. Manufacturers keep plant partially employed with difficulty, and generally the situation leaves a vast deal to be desired, but it is some gratification to learn that undercutting for foreign orders is somewhat less keen, and that there is a little more doing in sheets, while inquiry for constructional steel shows slight improvement. Foreign business can still be put through at substantially below the following rates which rule for home trade :—Common iron bars, 12*l.* ; iron rivets, 14*l.* ; steel billets (soft), 7*l.* 10*s.* ; steel billets (medium), 8*l.* 15*s.* ; steel billets (hard), 9*l.* 5*s.* ; steel boiler plates, 14*l.* 10*s.* ; steel ship, bridge and tank plates, 10*l.* 10*s.* ; steel angles, 10*l.* ; steel joists, 10*l.* 10*s.* ; heavy sections of steel rails, 9*l.* 10*s.* ; fishplates, 14*l.* 10*s.* ; black sheets, 13*l.* ; and corrugated galvanised sheets, 16*l.*

Foreign Ore.—Business in foreign ore is very quiet. Best rubio is round about 27*s.* c.i.f.

Coke.—Supply of coke is somewhat less scarce and prices are slightly easier, but nothing below 29*s.* is named for average blast-furnace Durhams delivered.

NOTES FROM SOUTH YORKSHIRE.

SHEFFIELD, Wednesday.

Iron and Steel.—The Engineers' lock-out has made more pronounced the feeling of unsettlement in the local staple trades. The lock-out has so far been restricted to 4,000 members of the Amalgamated Engineering Union in Sheffield and district. Extremists are trying to persuade members of kindred unions to "down tools" in sympathy, but so far the picketing of works has had little success. If, by the ballot which is proceeding, the other unions concerned decide to support the Amalgamated Engineering Union on the main principle of management, lock-out notices will be served on 35,000 metal workers in the Sheffield area, and iron and steel production will be suspended completely. Meanwhile business is of a distinctly scrappy character. The only activity of any moment is in hematite pig-iron for export, and in steel scrap. Electric steel furnaces have increased their output, and could do with larger tonnages of turnings. Large stocks of these are held by merchants, who, however, are pressing for higher rates than now obtain. The continued failure of British railways to come forward with substantial orders for renewals is reacting unfavourably on the rail, tyre and spring departments. Competition in springs is particularly severe not only from foreign countries but from districts in other parts of this country. Rolling mills are working to about one-third of their capacity on hand-to-mouth orders, while failure to replace expiring contracts has increased the seriousness of the position at the heavy forges and foundries. Minor orders for steel parcels have this week been booked with India, South Africa and Australia, and inquiries for tools and light steel products are rather more numerous from the far Eastern markets, but on the whole there is a dearth of forward buying. The widespread extension of steel and engineering shops during the war is now reacting on progress in the building trade. In all departments the basis of output is far larger than is necessary to meet current requirements. Business in tools for shipbuilding and engineering purposes has suffered a further relapse owing to the current lock-out. Wide variations in quotations for ferro-alloys are due to the forced unloading of stocks. Tungsten is being sold at less than the current cost of production.

South Yorkshire Coal Trade.—A further contraction in home business is to some extent counterbalanced by the sustained improvement in the export demand for steam hards and blast furnace coke. Good prices are being paid for the latter, in some cases ranging to as much as 5*s.* per ton above inland rates. The home industrial demand is exceptionally quiet. No improvement is

expected until the atmosphere has been cleared in the engineering trade. Gas companies' requirements are smaller with the lengthening days, but there is still a strong demand for best quality house coal. Most of the local collieries have sufficient orders on their books to warrant the continuance of full time working. Quotations:—Best branch handpicked, 38*s.* to 39*s.*; Barnsley best Silkstone, 36*s.* to 37*s.*; Derbyshire best brights, 34*s.* 6*d.* to 35*s.* 6*d.*; Derbyshire best house, 33*s.* 6*d.* to 34*s.* 6*d.*; Derbyshire best large nuts, 28*s.* to 30*s.*; Derbyshire small nuts, 17*s.* to 19*s.*; Yorkshire hards, 23*s.* to 24*s.*; Derbyshire hards, 21*s.* 6*d.* to 22*s.* 6*d.*; rough slacks, 14*s.* to 15*s.*; nutty, 8*s.* 6*d.* to 10*s.* 6*d.*; smalls, 2*s.* 6*d.* to 6*s.* 6*d.*

NOTES FROM THE NORTH.

GLASGOW, Wednesday.

State of Trade.—The general trade throughout the country has lately been in a very dull state, and few industries have shown much sign of picking up yet. Orders all round have been poor and a want of confidence seems to prevail amongst buyers. Conditions have been bad enough lately, but now the outlook is very much worse through the lock-out in the engineering trade, and with the wages trouble in the shipbuilding trade not yet settled. It is barely a year since everything was dislocated through the dispute in the coal-mining industry, and if the engineers and shipbuilders should both happen to be out of employment now for any length of time the results will certainly be very disastrous to the country. Everyone had high hopes that before long business would be opening out and a general improvement would be perceptible, but quite a pessimistic feeling is all too prevalent this week.

Scottish Steel Trade.—In the steel trade of Scotland there is very little business passing this week and the industrial crisis is having its effect already. Home buyers are quite out of the market now except for odd lots of stuff, and if the present labour trouble lasts for even a few weeks operations at the steel works will gradually get less. Many of the shipyards will shortly be out of gear owing to the withdrawal of members of the Amalgamated Engineering Union, and the demand for plates has already become less. Structural firms are quiet and black sheets for the home market are in poor request. For export, however, there is rather more doing, and there are also some quite satisfactory inquiries in the market. Prices show little or no change, and are as follow: Ship plates, 10*l.* 10*s.* per ton; boiler plates, 14*l.* per ton; sections, 10*l.* per ton; and sheets, ¼ in., 11*l.* 15*s.* per ton, all delivered Glasgow stations.

Malleable Iron Trade.—In the bar iron trade of the West of Scotland there has been almost no change, and plant is moving very slowly. There are many sellers for anything on offer and keen competition is the order of the day. Production costs continue high and with the very keen prices often quoted the margin is at vanishing point, and the only excuse put forward is that the works are being kept moving. Inquiries from abroad are not very heavy yet, but show signs of improving. The price named for "crown" bars is 11*l.* 10*s.* per ton, delivered Glasgow, with export lots a shade easier.

Scottish Pig-Iron Trade.—The demand for Scottish pig-iron is not appreciably better this week, and as in other industries the trouble in the engineering trade will not improve matters. Meantime hematite iron is slow of sale because of the dull state of the steel trade and foundry iron is also in poor demand. Export lots are far from satisfactory, and although hopes of improvement in that direction are prevalent there is so far little business going through. Prices are as under:—Hematite, 5*l.* 7*s.* 6*d.* per ton, delivered at the steel works; foundry iron, No. 1, 5*l.* 2*s.* 6*d.* per ton, and No. 3, 4*l.* 17*s.* 6*d.* per ton, in trucks at makers' yards.

NOTES FROM THE SOUTH-WEST.

CARDIFF, Wednesday.

The Coal Trade.—Exports of coal from South Wales in February, according to official returns, amounted to 1,125,643 tons, or 157,607 tons less than in the previous month. Average prices, including contract quantities, were again lower at 28*s.* 4½*d.* per ton f.o.b., a drop of 3*s.* 11½*d.* Shipments from Cardiff totalled 786,773 tons, from Newport 236,642 tons, from Port Talbot 52,525 tons, and from Swansea 49,703 tons. The average declared price of coal exported from Cardiff was 25*s.* 4*d.*, or 1*s.* 7*d.* less than in January; from Newport 23*s.* 11*d.*, a drop of 3*d.*; from Port Talbot 25*s.*, a fall of 3*s.* 4*d.*; and, from Swansea, 39*s.* 3*d.*, a reduction of 10*s.* 4*d.* The heavy decreases recorded at Port Talbot and Swansea were the result of the slump in the demand for anthracite coals. Export from South Wales in the past week totalled over 528,000 tons, which is the largest quantity shipped in any similar period of the past three years, but still 90,000 tons less than the volume of trade touched in the corresponding week of 1913. It is reported that the Bombay and Baroda Railway have placed their order for 170,000 tons of Welsh coal with one firm. Delivery is to be made at Bombay or Karachi over the last six months of the year, and it is understood that the business has been taken on the basis of 46*s.* c.i.f. for best Admiralty large and 45*s.* 6*d.* for second Admiralty large. Basing the freight to Bombay at 20*s.*, these prices are about 1*s.* 6*d.* per ton below current market values. Meanwhile prices are firmly upheld on the basis of 27*s.* 6*d.* for best Admiralty large and 19*s.* 6*d.* for best steam smalls. A number of collieries are fully sold for this month and into April, while some have booked up orders for May delivery at current values.

The Trade Depression.—The effects of the three months national coal strike and the trade depression are strikingly illustrated by the enormous decrease which has taken place in the profits of Welsh colliery companies. The reports of three important colliery owning companies for the year ended December 31 last have just been issued. That of D. Davis and Sons, Limited, shows that a profit of 33,663*l.* was made compared with 221,088*l.* in 1920, while the dividend to ordinary shareholders has been reduced from 20 per cent. to 7½ per cent. The profits of the Welsh Navigation Steam Coal Company, Limited, has been reduced from 129,535*l.* in 1920, to 7,288*l.*, and the dividend from 10 per cent. to 5 per cent. The Cardiff Collieries, Limited, sustained a loss of 3,471*l.*, which compares with a profit of 76,753*l.* in 1920, and the dividend of 20 per cent. was reduced to 10 per cent. Thus three companies show a decrease in their profits of 389,896*l.*

BRITISH IRON AND STEEL PRODUCTION.—The production of pig-iron in February amounted to 300,100 tons, a figure higher than has been reached in any month since the coal stoppage began, but less by 163,500 tons than the production of the corresponding month last year. The furnaces in blast at the end of February numbered 101, compared with 90 at the end of January and 193 at the end of February, 1920. Of the production of pig-iron in February, 101,800 tons were hematite, 90,100 tons basic, 69,000 tons foundry and 20,000 tons forge. The production of steel ingots and castings in February amounted to 415,000 tons, compared with 327,500 tons in January and 483,500 tons in February, 1921.

THE LATE DR. ING. L. SYMPHER.—Dr. Leo Sympher, who died last month, was an eminent hydraulic engineer, and one of the foremost pioneers of the modern German canal policy. Born in 1854 at Münden, in Hanover, where the Rivers Werra and Fulda unite to form the River Weser, and where Papin's first steam-propelled paddle-wheel boat came to grief in 1707, Sympher entered the Navy as a cadet, but had to leave it soon owing to defective eyesight. He then studied at the Technical High School in Hanover and joined the Prussian Government service as hydraulic engineer. He had a large share in the construction of the Kiel-Brunsbüttel Canal through Holstein, and his name was mentioned in our columns when we published the first technical description of that canal. Later on he was mainly responsible for the project of the Rhine-Weser Canal, the building of which the war prevented, and for the varied negotiations this scheme involved. His dignified bearing contributed much to his success in negotiations. Emphasising the importance of developing water power in connection with canal construction he was also much interested in the South German Canal projects which have been promoted since the war.

MANCHESTER ASSOCIATION OF ENGINEERS.—At a meeting of the Manchester Association of Engineers held on Friday, the 10th inst., Mr. William Fox, chief mechanical engineer for the Manchester Ship Canal Company, read a paper upon "Some Engineering Developments in the Manchester Ship Canal." In this he described the plant used in dredging and pumping operations, the 60-ton floating crane recently installed, and the facilities provided for the handling of grain. The No. 2 grain elevator, he stated, was the most modern in the country and 40,000 tons of grain could be stored in the bins. The weight of the building and machinery above the ground (apart from the grain stored) was 120,000 tons. Many large ports with a much greater quay area handled far less tonnage, the density of traffic over the Manchester quays being quite exceptional. Several speakers, including Mr. E. Latimer, the managing director of the canal company, gave interesting reminiscences of the inception and early stages of the project. Mr. J. P. Bedson said that among the men whose services ought not to be forgotten Mr. Daniel Adamson was pre-eminent, and it would be a fitting memorial of him if the Ship Canal Company called its largest dock the Daniel Adamson Dock.

MINERS' WELFARE FUND.—The committee appointed by the Secretary of Mines to allocate the fund constituted under Section 20 of the Mining Industry Act, 1920, held a meeting on February 28, under the chairmanship of Viscount Chelmsford, at which the first allocations of money from the fund were made. Among the grants voted were 12,000*l.* to provide for important research work in connection with (*a*) miners' safety lamps, both flame and electric; and (*b*) coal dust dangers; also the preparation of abstracts of research data both in this country and abroad. The sum of 1,000*l.* was voted towards research in connection with the control of atmospheric conditions in deep and hot mines. All these research activities will be carried on under the supervision of the Mines Department. A grant of 3,000*l.* was made, on the recommendation of the Joint Welfare Committee of Coalowners and Workmen for the Warwickshire District, towards the provision of additional lecture room and laboratory accommodation at the Nuneaton County Mining School, where the existing premises are proving quite inadequate for the rapidly increasing numbers of miner students. On the recommendation of the Joint Welfare Committee for the Forest of Dean District, various smaller grants were made in aid of local recreational schemes, such as the equipping and laying out of cricket and football grounds, &c.

NOTICES OF MEETINGS.

THE INSTITUTION OF MECHANICAL ENGINEERS.—Friday, March 17, at 6 p.m., at the Institution, Storey's Gate, St. James' Park, S.W. "British and American Locomotive Design and Practice," by P. C. Dewhurst, of Kingston, Jamaica, Member.

THE ROYAL SANITARY INSTITUTE.—Friday and Saturday, March 17 and 18, at 6 p.m., in the Public Hall (north gate entrance), Blackburn, when discussions will take place on "The Sanitation of Places of Entertainment," to be opened by Mr. W. Allen Daley, M.D., B.A., B.Sc., D.P.H., Medical Officer of Health, Blackburn, and on "The Conversion of Pail Closets," to be opened by Mr. A. T. Gooseman, M.Inst.C.E., Borough Engineer, Blackburn.

THE ASSOCIATION OF ENGINEERS-IN-CHARGE.—Saturday, March 18, at 7.30 p.m., at St. Bride's Institute, Bride-lane, Fleet-street, E.C. 4. Informal Discussion Evening to discuss "The Merits of Diesel and other Oil Engines for Industrial Work." Visitors are invited to be present and take part in the discussion.

THE BRADFORD ENGINEERING SOCIETY.—Monday, March 20, at 7.30 p.m., Joint Meeting with the Institution of Mechanical Engineers (Yorkshire Association) in the Hall of the Bradford Technical College. Lecture by Professor G. F. Charnock, M.I.Mech.E., on "The Heat Extraction Engine," illustrated by lantern slides.

THE INSTITUTION OF CIVIL ENGINEERS: YORKSHIRE ASSOCIATION.—Monday, March 20, at 7.30 p.m., Students' Meeting in the Hotel Metropole, Leeds, when Mr. N. K. Holmes, Stud.Inst.C.E., will read his paper entitled "Modern Methods of Water Purification."

THE ROYAL SOCIETY OF ARTS.—Monday, March 20, at 8 p.m.: Cantor Lecture, "The Constituents of Essential Oils," by Mr. L. Guy Radcliffe, M.Sc.Tech., F.I.C., Lecturer in Applied Organic Chemistry, College of Technology, Manchester. (Lecture I.) Wednesday, March 22, at 8 p.m.: Ordinary Meeting, "The Late Mr. Holman Hunt's Experiments on the Permanency of Artists' Oil Colours," by Professor A. P. Laurie, M.A., D.Sc., F.R.S.E., H.R.S.A., Professor of Chemistry to the Royal Academy of Arts. Sir Aston Webb, K.C.V.O., C.B., P.R.A., will preside. Friday, March 24, at 4.30 p.m.: Indian Section, "The Indigo Situation in India," by Professor Henry E. Armstrong, Ph.D., LL.D., D.Sc., F.R.S. Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., will preside.

THE INSTITUTION OF CIVIL ENGINEERS.—Tuesday, March 21, at 6 p.m. Paper to be read: "All-Electric Automatic Power Signalling on the Metropolitan Railway," by Mr. William Willox, M.A., M.Inst.C.E.

THE INSTITUTE OF COST AND WORKS ACCOUNTANTS.—Wednesday, March 22, at 7 p.m., at the Hall of the Institute of Chartered Patent Agents, Staple Inn Buildings, Holborn. An address will be given by Sir Herbert Austin, K.B.E., M.P., on "Costing at Longbridge Works." The chair will be taken by Captain H. Riall Sankey, C.B., C.B.E., R.E.(Ret.), M.I.Mech.E.

NORTHAMPTON ENGINEERING COLLEGE ENGINEERING SOCIETY.—Thursday, March 23, at 5.30 p.m. Paper on "Electric Locomotives," by Mr. R. E. Dickinson (London and North-Western Railway).

THE INSTITUTION OF ELECTRICAL ENGINEERS.—Thursday, March 23, at 6 p.m., at the Institution, Savoy Place, Victoria Embankment, London, W.C.2. Discussion on the "Draft B.E.S.A. Specifications for Motor Starters."

THE INSTITUTION OF LOCOMOTIVE ENGINEERS (LONDON).—Thursday, March 23, at 7.15 p.m. sharp, at Caxton Hall, a paper will be read by Mr. A. E. Howell, Member, Newcastle-on-Tyne, entitled "Modern Production and Costing Methods as applied to Locomotive Engineers."

THE ROYAL INSTITUTION OF GREAT BRITAIN.—Friday, March 24, at 9 p.m., an address will be delivered by Professor F. G. Donnan, C.B.E., D.Sc., F.R.S., M.R.I. The subject is "Auxiliary International Languages." Afternoon Lectures, at 3 p.m.: Tuesday, March 21, Sir Arthur Keith, M.D., LL.D., F.R.S., M.R.I., Fullerian Professor of Physiology, R.I., on "Anthropological Problems of the British Empire: Series I.—Racial Problems in Asia and Australasia" (Lecture V); Thursday, March 23, Mr. P. Chalmers Mitchell, C.B.E., I.L.D., D.Sc., F.R.S., Secretary, Zoological Society, on "The Cinema as a Zoological Method" (Lecture II); Saturday, March 25, Sir Ernest Rutherford, LL.D., D.Sc., F.R.S., M.R.I., Professor of Natural Philosophy, R.I., on "Radio-activity" (Lecture IV).

THE INSTITUTION OF ELECTRICAL ENGINEERS.—At the invitation of the committee of the Scottish Centre a summer meeting of the Institution will be held at that centre from May 30 to June 2 next. The programme is substantially the same as that of the meeting arranged for last year (abandoned on account of the coal strike). Further information can be obtained from the secretary of the Institution, Savoy-place, Victoria Embankment, London, W.C. 2.

THE INDUSTRIAL LEAGUE AND COUNCIL.—Mr. G. N. Barnes, M.P., the well-known Labour leader, will give an address on "Some Common Fallacies in Trade and Industry" at a meeting to be held at the Caxton Hall, Westminster, on Wednesday next, the 22nd inst. The meeting is one of a series arranged by the Industrial League and Council. The meeting will begin at 7·30 p.m.

THE THORNYCROFT CONTINUOUS SUGAR BEET DIFFUSER

CONSTRUCTED BY MESSRS. JOHN I. THORNYCROFT AND COMPANY, LIMITED, ENGINEERS, BASINGSTOKE.

(*For Description, see Page* 315.)

FIG. 40.

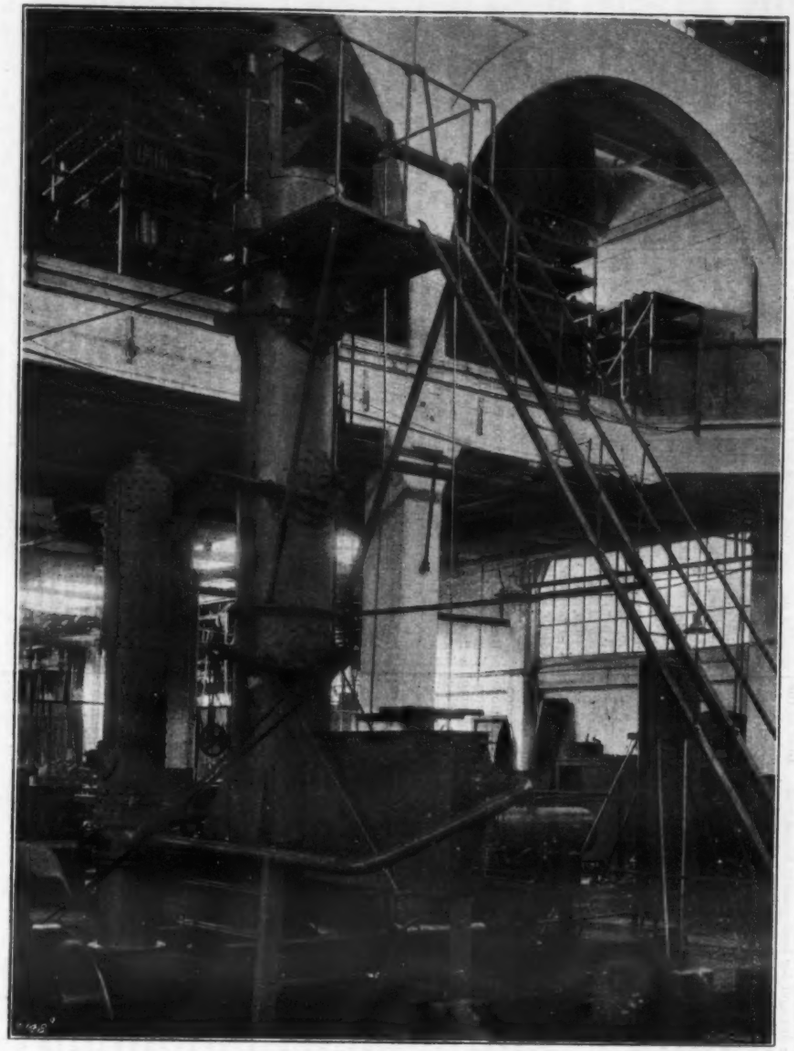


FIG. 41.

ENGINEERING.

Offices for Publication and Advertisements 35 and 36, Bedford Street, Strand, London, W.C. 2.

We desire to call the attention of our readers to the fact that the above is our SOLE ADDRESS, and that no connection exists between this Journal and any other publications bearing somewhat similar titles.

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Advertisements intended for insertion in the current week's issue must be delivered not later than First Post on Thursday. In consequence of the necessity of going to press early with a portion of the edition, alterations for standing advertisements should be received on the Friday previous to the day of publication.

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Two-Page Plate.—THE THORNYCROFT CONTINUOUS SUGAR BEET DIFFUSER.

ENGINEERING.

FRIDAY, MARCH 17, 1922.

THE ENGINEERING DISPUTE.

THE lock-out in the engineering industry has now been in operation for the best part of a working week, and it may thus be of advantage to set out as clearly as possible the position taken up by the two parties to the dispute, viz., the Engineering and the National Employers' Federations, on the one hand, and the Amalgamated Engineering Union, on the other. This is the more important as it raises questions of national importance and of far-reaching effect on all industries and on our supremacy as a manufacturing nation. Indeed, in view of the absolute necessity for exports in order to secure supplies of food and raw material it is not too much to say that the attack which the dispute involves on the successful conduct of our factories for the production of manufactures to be shipped constitutes a menace to our influence as a State of world importance.

Historically viewed, the trouble originated with the question of overtime, but the action which the employers have taken is not due to an overtime dispute. It has been rendered necessary by the union's challenge of their right to retain the managerial control of their works. With this in mind we may deal with the subject in the chronological sequence of the events. In September, 1920, the federations and the union entered into an agreement that no union workman should be required to work more than 30 hours overtime in any four weeks, subject to a proviso that overtime was not to be restricted in the case of breakdowns, repairs, replacements, alterations, trial trips, and the completion of work against delivery dates. This was not altogether a new agreement, because in 1898 the employers had agreed to a maximum of 40 hours overtime in any four weeks, which was reduced to 32 in 1907, and the effect of the agreement of 1920 was merely to reduce the maximum to 30 hours in four weeks. The agreement was balloted upon by the members of the union, and was accepted, but immediately thereafter the Executive Council of the union issued instructions to their district officials that overtime was not to be permitted unless the representatives of the workmen had previously been consulted and had agreed to it. These instructions completely altered the whole position, as it raised a much wider issue than the incidental question of overtime. If the federations had acquiesced in the position taken up by the union they would have abrogated the principle of the right to conduct the factory in accord with the requirements of industry. In effect, they would have given the union a right to veto overtime whenever they thought fit, and this might have led to further interference. The fact that the employers forebore to take drastic steps at the time is evidence that the present dispute is not one which affects merely the question of overtime.

As a result of the Union's instructions to their local officials, much local friction occurred, and prolonged negotiations ensued between the federations and the union. In November, 1921, it became apparent to the employers that the real aim of the union was to secure a right of controlling managerial functions and a right of vetoing managerial acts when they thought fit to do so. The issue was accordingly raised by the union to one of fundamental importance. The employers, feeling that their whole position was at stake, took up the challenge and made it plain to the union in the prolonged discussions which ensued that they could not relinquish the managerial control of the works or permit the union to have a right of veto. They were perfectly willing to discuss with the union any objections which might be raised to any managerial acts, but they could not allow the management of the works to be hampered or impeded by anything in the nature of a veto on the part of the union. In other words, proposed actions of the management were not to be delayed until the unions agreed to them, but were to be proceeded with unless and until the employers agreed in conference with the union to give effect to any objections or representations on the part of the union.

At a conference on November 17 and 18, 1921, after matters appeared likely to come to a climax, the position was eased by the executive council and the national and divisional organisers of the union agreeing to recommend to their members an agreement. The general clauses laid it down firstly that the trade union shall not interfere with the right of the employers to exercise managerial functions in their establishments, and the federations shall not interfere with the proper functions of the trade union; secondly, that in the exercise of these functions, the parties shall have regard to the provisions for avoiding disputes of April 17, 1914, which are amplified by the shop stewards and works committee agreement of May 20, 1919, and to the terms of other national and local agreements between the parties; and thirdly, that instructions of the management shall be observed pending any question in connection therewith being discussed in accordance with the provisions referred to.

As regards the question of overtime, the terms were equally explicit and mutually acceptable. "It is agreed that in terms of the overtime and night shift agreement of September 29 and 30, 1920, the employers have the right to decide when overtime is necessary, the workpeople of their representatives being entitled to bring forward under the provisions referred to any cases of overtime they desire discussed. Meantime, the overtime required shall be proceeded with."

The provisions for avoiding disputes referred to in the agreement constitute a code of procedure whereby questions in dispute between the parties may be discussed first of all locally and, if need be, in central conference between representatives of the federations and representatives of the union. In the agreement the employers had maintained their position, and for the moment all seemed well. The agreement had to be ballotted upon, however, by the members of the union, and unfortunately the men turned down the recommendation of their executive council and national and divisional organisers. There was no haste about the ballot, the agreement is dated November 18, 1921, and the ballot was not declared until January 27, 1922. The employers say there is now, therefore, a clear issue between them and the union, viz., whether the employers have the right to exercise their managerial functions, or the industry is to be carried on under dual control or subject to a right of veto by the union.

Turning to the statement of the union's case

issued yesterday by its Executive Council, the first point which strikes us is that it confirms the employers' statement that the dispute is over the question of managerial rights. The union say: "The present dispute has been brought about by the employers insisting on managerial rights. The right they claim is the right to enforce overtime and other working conditions without consultation with the union's representatives." The second part of this quotation is clearly an over-statement, because (1) the references in the memorandum of the conference of November 17 and 18, 1921, to the provisions for avoiding disputes, show the willingness of the employers to confer with the unions, and (2) the Executive Council proceed to state that the unions want consultation before grievances arise, and the employers offer discussion after grievances arise. It seems clear from the union's own statement that they claim that acts of management of which they may not approve are not to be carried out until they have been consulted and have agreed to them. The statement commences by referring to the agreement of September, 1920, limiting overtime to 30 hours in four weeks. It states the interpretation put upon the agreement by the union executive that there must be joint consultation between the management and the local union officials before overtime on production work is worked; that the employers challenged that interpretation and intimated in April, 1921, that if the union adhered to it they would be compelled to dispense with the services of the members of the union; that nevertheless the employers delayed taking such a drastic step; that eventually, on November 17, 1921, the Executive of the union agreed to recommend their members to accept the memorandum which we have quoted; that a ballot of 20 per cent. of their members was adverse to the recommendation of their executive, and that on February 17, 1922, fourteen months after the overtime issue was first raised, the employers announced their resolve to lock out the members of the union on March 11, 1922, and at the same time published their intention to bring under review not only the question of wages and working conditions, but the whole question of their relations with the workers.

Having dealt with these facts the union's statement proceeds to what we can only term special pleading. They say that the employers are seeking to misrepresent the causes of the dispute; but as we have already indicated, the cause of the dispute appears plain from the statements of both parties. The union state that the employers are not only seeking to limit the rights of trade unions to safeguard and promote the legitimate rights of their members, but, in order to advance their own interests are encouraging men to desert from the Amalgamated Engineering Union. This the employers have categorically denied. The union states also that the employers reject the men's claim to consultation in advance regarding questions of overtime because it would interfere with the rights of management, and they maintain that the employers' real reason is that they are determined that the men shall have no voice whatever in deciding questions of overtime on production work. If that were so the employers would scarcely have agreed with the union in 1920 to restrict overtime to 30 hours in four weeks.

One question which the union do not deal with in their statement is the vital question how the management of the works is to be carried on if, before the management act, there must be prior consultation with the union officials. In all industries questions of management must be decided promptly as soon as they arise, and it seems to us that the union's claim to prior consultation clearly amounts to a negation of the right of management, and involves dual control to which the employers could certainly never agree.

THE NAVY ESTIMATES.

ALTHOUGH the estimated naval expenditure for the year 1922–23 shows a net reduction of 17,595,300*l.*, or over 21 per cent. in comparison with that for the current year, the total sum required, viz., 64,883,700*l.*, still exceeds that considered to be necessary by the Geddes Committee on National Expenditure by nearly 5,000,000*l.* Moreover, the economies proposed by the Geddes Committee did not include those rendered possible by the Washington Conference, which are included in the Admiralty's estimates and have had a material effect in reducing them. For instance, had the four new battle cruisers been proceeded with, sums of 10,557,800*l.* and 1,259,000*l.* would have been required during the ensuing year for the construction of those vessels and their armaments, respectively, whereas the two ships to be constructed in accordance with the Conference agreement will not be commenced until shortly before the end of the year, and the total sum allowed for them is only 721,500*l.*

To adjudicate effectively between the divergent views of the committee and the Admiralty as to the exact amount of naval expenditure to be allowed would involve a wider knowledge of facts and circumstances than is available to the general public, and that being so it would appear to be necessary either to accept the figures of the Admiralty or to have them investigated further by some competent authority. It must be remembered, however, that it is the Admiralty who are responsible for carrying out the naval policy of the Government, and they estimate the above-mentioned sum as the absolute minimum with which that policy can be pursued. In the explanatory statement accompanying the estimates, the First Lord states that drastic economies and consequent risks have been accepted which can only be justified on the assumption that the British Fleet will not be engaged in any great war for many years to come. This assumption, of course, is only possible in view of the improved international situation, and even so is only warranted on account of the existing extreme financial stringency. It must also be understood that certain of the proposed economy measures, especially those connected with fuelling facilities, cannot fail to affect the efficiency of the Fleet. These must certainly be regarded as of a temporary character only, and be abandoned as soon as the financial situation becomes easier, since it is obvious that in the future our reduced Fleet must be maintained at an even higher standard of efficiency than has been necessary in the past.

Coming now to the actual economies to be effected as set out in the First Lord's Memorandum, we note that the present estimates provide for a reduction of the *personnel* of the Fleet from 118,500 to 98,500 during the ensuing financial year. It is also stated that in addition to the 20 capital ships to be scrapped in accordance with the Washington Treaty (9 of which have already been disposed of) it is intended to scrap the battleship Collingwood, and to put the battle cruiser Renown into reserve on her return to this country with H.R.H. the Prince of Wales. The main Atlantic Fleet will then be composed of one fleet flagship, two divisions of four battleships each, and two battle cruisers. The Mediterranean Fleet consists of only four battleships, and the Admiralty state that they are satisfied that the total number of capital ships to be retained in commission is the minimum necessary for training the *personnel*. The number of light cruisers attached to the Atlantic Fleet will not be reduced since some of these vessels are frequently detached from the Fleet for long periods on special duties, but the light cruiser strength of the African Squadron will be reduced to two ships by keeping the Birmingham in reserve at home. With regard to destroyers, it will be remembered that one of the flotillas belonging to the Atlantic Fleet was reduced to two-fifths complement last year for reasons of economy, and with the same aim only, another flotilla is now to be similarly reduced. This will bring the number of destroyers in full complement with the Atlantic Fleet down to 40, which is considered to be the minimum possible for carrying out fleet exercises and training officers and men. From the local-defence flotillas, already on a reduced complement, another 23 destroyers will be put to reserve. Of the 85 submarines previously maintained, it is now proposed to abolish 27, and the number kept in full commission will be reduced from 46 to 40 by keeping six vessels of this class in reserve on the China Station.

Dealing with the votes *seriatim* we note that 15,822,000*l.* is required for pay, 5,827,000*l.* for victualling and clothing, 529,000*l.* for the medical services and 285,000*l.* for civilians employed on fleet services. In comparison with the current year, these four votes show an aggregate reduction of 4,781,500*l.*, which is largely due to the reduction in naval *personnel* above referred to, but is also affected by the fall in the cost of living which has enabled the men's marriage allowance and other similar allowances to be reduced. For education and the scientific services 397,500*l.* and 395,000*l.* are required, respectively, the two votes together being lower by 122,000*l.* than those for the current year. A considerable part of this saving has been effected by reductions in the cost of the Royal Naval College, Dartmouth, and by increasing the fees payable in connection with the entry of cadets.

The cost of the naval reserves, viz., 552,300*l.*, will be 28,300*l.* lower than has been the case this year, but that section of Vote 8 relating to dockyard *personnel* shows a saving of 3,849,800*l.*, the figure for the ensuing year being 7,995,800*l.* This vote provides for the discharge of over 10,000 men from the dockyards at home and abroad, but Rosyth is the yard most affected, it having been decided to place this establishment on the footing of a docking yard only. Chatham Dockyard will be retained, and, for the present, it has been decided not to reduce Pembroke further than was announced last year, *i.e.*, to a strength of 1,200 men; Gibraltar Dockyard will, however, be considerably reduced. It is pointed out that the dockyard reductions involve the delay or abandonment of much important work and are made only as a temporary measure to tide over the present financial situation. Section II of Vote 8, relating to *matériel*, amounts to 7,246,000*l.*, and shows a net reduction of 4,837,500*l.* in comparison with the corresponding figure for the current year. The saving is due to the fall in prices of oil fuel and coal, and also to administrative action of a drastic nature. The allowance of fuel for the Fleet has been cut down to a minimum, and a number of fleet auxiliaries normally employed on fuelling work will be laid up; existing coal reserves will also be drawn upon to a large extent. It has also been decided to delay the progress with the scheme for providing oil fuel reserves at various bases abroad and the expenditure for this work will be reduced by 500,000*l.* This is obviously a serious step since the mobility of the chief units of the Fleet is at present considerably restricted by the absence of oil-fuelling bases.

The remaining section of Vote 8, relating to contract shipbuilding amounts to 3,341,500*l.*, which is 2,304,700*l.* less than that for the current year, while the separate vote for naval armaments, which stands at 5,088,800*l.*, shows a reduction of 1,837,200*l.* We have already pointed out how these two votes are affected by the cancellation of the orders for the four battle-cruisers, and the substitution for them of the two smaller vessels in accordance with the terms of the Naval Treaty of Washington. Large reductions in the vote for armaments have also been effected by deferring the overhaul and reconditioning of surplus stocks of ammunition, by decreasing the reserves of mines and depth charges and by delaying the completion of the equipment of the Fleet with armour-piercing shell.

The estimated expenditure on works, buildings and repairs has been reduced to a minimum by restricting it almost entirely to those works actually in hand, the stoppage of which would involve considerable expenditure for compensation or for reconditioning sites, and to those works which can be completed at a comparatively small cost. Other expenditure is unavoidable in cases which involve the safety of structures or the usability of docks, wharves or important machinery. In certain cases also the Admiralty is committed by legal obligations, and a minimum allowance must, of course, be made for ordinary repairs and maintenance. The total sum required under this heading amounts to 4,273,000*l.*, and the reduction is 1,573,600*l.*

The remaining votes are as follows: For miscellaneous effective services 1,633,500*l.*, a reduction of 1,091,500*l.*; for the Admiralty office 1,387,800*l.*,

reduction 365,000*l.*; and the non-effective services for which three votes totalling 10,109,500 are required. The latter figure shows an increase of 3,195,800*l.*, in comparison with that for the current year, but it must be remembered that the non-effective charges will be largely augmented by the discharge of over 30,000 officers and men from the Navy and dockyards during the year.

RADIO-ACTIVITY.

AT the Royal Institution, on Saturday afternoon last, Sir Ernest Rutherford, F.R.S., delivered the second lecture* of his course on the above subject. He stated that, at the close of the last lecture, he had pointed out that radium was peculiar in the sense that the quantity of it contained in a sealed tube could be measured without opening the tube. This was possible because certain of the radiations emitted by the element were very penetrating. Indeed, they would pass right through the human body or through a few feet of earth. This property had been frequently made use of for the discovery of lost radium. In one case radium worth 1,000*l.* which had been used for treating a patient was on a subsequent inventory found to be missing. A search was made and the patient X-rayed on the hypothesis that he might have swallowed it, but in vain. It was then discovered that refuse had been carted away from the hospital shortly before the radium was missed. The carter was interrogated, and gave a rough indication as to the part of the city dump where he had shot the rubbish. A charged electroscope was then brought to the dump and the position found at which it most rapidly lost its charge. It was then known that the radium was below, and, by testing with the electroscope each bucketful removed, the radium was recovered.

Sir Ernest Rutherford next referred to the use of radium for making visible at night compass points and gun sights. This was effected by coating them with a mixture containing zinc sulphide and a small proportion of radium. The luminosity thus obtained was not quite permanent, owing to the interesting fact that the α particles, emitted by the radium, bombarded the crystals of the zinc sulphide with such intensity that they destroyed the inner crystalline structure of the sulphide, with the result that the phosphorescence decayed fairly rapidly. This decay was, however, it would be seen, due to a secondary effect and not to loss of radium. Actually, he understood that the salvage departments had recovered after the war nearly a gramme of radium from superfluous sights and compasses. Sir Ernest suggested that, in view of the decay of the luminosity due to the destruction of the crystals of zinc sulphide, it would be better to use meso-thorium for such purposes. This was much cheaper than radium, and the α particles it emitted were somewhat more penetrating. The much shorter life of this body would not matter, as it would only be in use for a year or so.

Radio-active bodies, Professor Rutherford proceeded, emitted three distinct types of radiation, which he had named the α, the β, and the γ rays. In some respects the α rays were by far the most important. They consisted of a stream of positively electrified atoms of helium, which were shot out from the radio-active element at a very high velocity. This velocity was, in fact, generally of the order of 10,000 miles per second. The β rays were very swiftly-moving electrons, and the γ rays were light rays of the X-ray type. All three of these spontaneously produced radiations possessed enormously greater energy than the corresponding radiations which could be produced artificially in the laboratory. Thus the α rays from radium had a kinetic energy incomparably greater than the corresponding positive rays studied by Sir J. J. Thomson. The electrons constituting β rays, again, were very much swifter than the cathode rays produced in a vacuum tube, and the γ rays had enormously greater penetrative powers than any X-rays so far generated. Comparing the three types of radiation *inter se*, Sir Ernest said that the energy of the α particles was very much greater than that represented by the β or γ rays. The ionisation produced by an α particle was accordingly on the average at least 100 times as great as that effected by a β particle, but, although swift, the α particles lost speed very rapidly, their extreme range in air at standard temperature and pressure being 10 cm. to 11 cm. as a maximum. They could, nevertheless, produce enormous ionisation, since though their penetrative power was small, their energy was very great. They were, however, unable to pass through a thin sheet of notepaper, as the lecturer showed by interposing such a sheet between a Zeleny electroscope (see Fig. 1, page 299, of our last issue) and a copper plate on which polonium had been deposited.

What, Sir Ernest proceeded, was the cause of this remarkable behaviour of the radio-active elements in expelling these most penetrating and

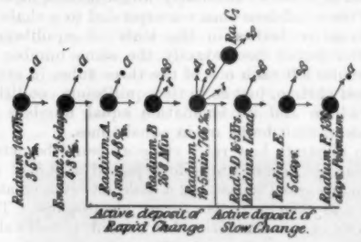


FIG. 2.

Fig.6.

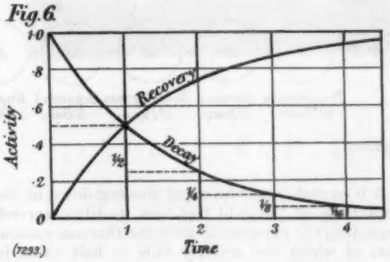
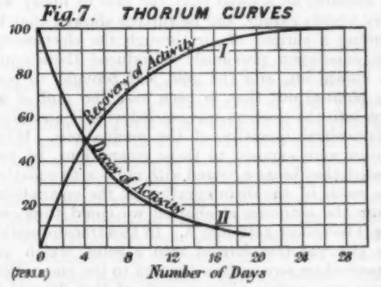


Fig.7. THORIUM CURVES



previously unknown radiations? The theory was given by himself and Soddy nearly 20 years ago as the result of experiments made at Montreal, and was based upon the following simple ideas:—Atoms of ordinary elements such as iron or gold were permanent, lasting for billions of years, but in order to explain the results of their observations on thorium they assumed that the atoms of radio-active elements differed from ordinary atoms in one respect and in one respect only. They were not permanently stable. At any moment of time a certain fraction of the atoms of these elements became unstable. An atomic explosion occurred, as the result of which either α or β particles were shot out, and the residue of the atom left constituted an atom of an entirely different element. Thus the atom of radium broke up into an α particle and an atom of the emanation. The atomic weight of radium was 226. That of the α particle, which was an electrified helium atom, was 4. Hence the atomic weight of the emanation was 226 − 4 = 222. The interesting point was that the emanation was entirely different from its parent. Radium was a solid with distinctive chemical properties closely resembling those of barium. The emanation, on the other hand, belonged to the family of rare gases devoid of marked chemical properties. The transformation accordingly gave rise to an entirely new substance, which turned out to be far more unstable than its parent, and accordingly broke up in its turn with the expulsion of a second α particle (see Fig. 2, which we repeat from our last week's article). The residue after this explosion had an atomic weight of 222 − 4 = 218, and was known as radium A, which was again a solid and a metal. The atoms of radium A were very unstable and broke up very fast to yield radium B. This atom was also unstable, but when it exploded the particles emitted were not α particles, but β particles, *i.e.*, swiftly moving electrons. In most cases, indeed, an exploding atom emitted either α or β particles; but, as would be seen from Fig. 2, the atoms of RaC, which resulted from the break up of the RaB atoms, appeared to give out all three types of radiation, viz., α, β and γ. On this point he would have more to say in his next lecture. On reference to Fig. 2, it would be seen that we had a whole chain of consecutive changes of one atom into another. If the view were correct that the phenomena observed were due to transformations occurring within the atom, it became important to know the law of the rate of change. Investigation showed that if we took polonium for example, its activity as measured electrically, fell in 136 days to one-half its original value. In another 136 days its activity was again halved, being then one-quarter of the original amount; and after the lapse of a third period of 136 days the activity was found to have again been halved, and was thus equal to one-eighth the initial value. It would thus be seen that the activity of radio-active substances fell off according to the exponential law, which moreover held universally and was independent of all chemical and physical conditions. The rate of change was identically the same at furnace temperatures and at that of liquid helium, and was also quite unaffected by chemical conditions. In the case of one radio-active body he had confirmed the law till the activity fell to $\frac{1}{10,000,000}$ of the initial value. If instead of working with a single substance like polonium we had a whole chain of successive changes, then in the condition of equilibrium, an equal number of atoms of each member of the chain must break up in unit time. When the atom of radium broke up, an atom of emanation was produced, and unless at the same time another atom of emanation exploded, there would be an increase in the number of atoms of the latter present, and the condition would not be one of equilibrium.

Suppose, however, we removed the whole of emanation and started with pure radium. Each atom of radium as it exploded produced an atom of emanation. For each atom of the parent body which disintegrated one atom of a radio-active descendant was formed, so that the total remained constant, as indicated in Fig. 6, where the sum of the ordinates of the decay and recovery curves was equal to unity throughout. Fig. 7 represented the curves actually obtained in the early experiments made with thorium X, from which the law governing the atom disintegrations was deduced. These laws were summed up in the following table:

TABLE I.—*Laws of Transformation.*

N_o = number of atoms initially.

N_t = number remaining after time t seconds.

Then $\frac{N_t}{N_o} = e^{-\lambda t}$ where λ is the radio-active constant.

T = Time for half transformation = $\frac{0{\cdot}693}{\lambda}$ seconds.

L = average life = $\frac{1}{\lambda}$ seconds.

$\frac{dN}{dt} = -\lambda N$

i.e., λ is the fraction of the total number of atoms which change per second.

Suppose substance	A →	B →	C
Number of atoms of each present	= P	Q	R
Corresponding transformation constants	λ_1	λ_2	λ_3

Then

$$\frac{dP}{dt} = -\lambda_1 P \quad . \quad . \quad . \quad (1)$$

$$\frac{dQ}{dt} = \lambda_1 P - \lambda_2 Q \quad . \quad . \quad . \quad (2)$$

$$\frac{dR}{dt} = \lambda_2 Q - \lambda_3 R \quad . \quad . \quad . \quad (3)$$

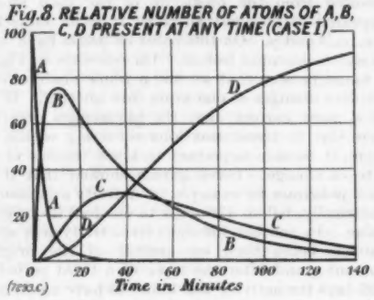
These three equations give the values of P, Q and R at any subsequent time, when the initial values are given.

* For an account of Sir Ernest Rutherford's first lecture see page 299 of our last issue.

The life of any individual atom of a radio-active body might be infinitely long or infinitely short, but by integrating the first of the equations given above after multiplication by t, it would be found that the average life L was, as stated, equal to $\frac{1}{\lambda}$. Further, by substituting in (2) the value of P expressed in terms of t and of the initial value, we could deduce a formula for the value of Q at any time t, and similarly with regard to R.

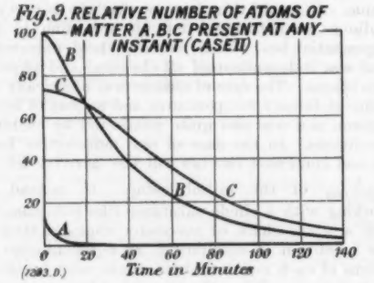
If, for example, we started with radium A which changed into radium B, this into radium C, and this into radium D, then the equations deduced as above

Fig. 8. RELATIVE NUMBER OF ATOMS OF A, B, C, D PRESENT AT ANY TIME (CASE I)



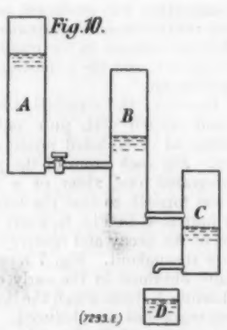
(7233.C)

Fig. 9. RELATIVE NUMBER OF ATOMS OF MATTER A, B, C PRESENT AT ANY INSTANT (CASE II)



(7233.D)

Fig. 10.



(7233.E)

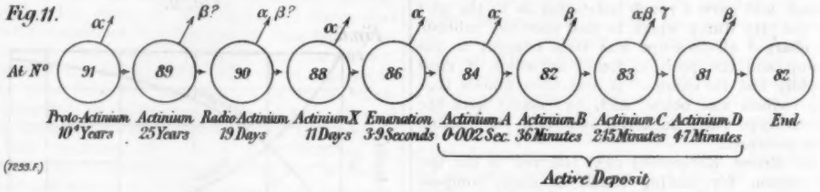
were in this case represented by the curves reproduced in Fig. 8, which showed the relative number of atoms of each present at any subsequent time. For each body the relative number passed through a maximum and then decayed, the final apparent rate of decay being in all cases fixed by that of the longest lived body in the chain. As another case, suppose the bodies, radium A, radium B and radium C in equilibrium with the emanation, in which case for each atom of the emanation that exploded, so did one atom of each of the derived substances. If now the emanation were removed, the equations in Table 1 could be integrated as before, but with different constants, and in that case the curves representing the relative numbers of the different atoms present were of a different character, having the forms represented in Fig. 9. In actual practice the relative number of atoms present could not be observed directly, but had to be deduced from the activities as measured electrically.

To illustrate the foregoing, Professor Rutherford had arranged an experiment, represented diagrammatically in Fig. 10, where A, B and C denote three wide glass tubes connected together by small-bore tubes. The tube A at the outset was filled with coloured water. The stopcock being opened, this flowed through the connecting tube into B, and thence through a second small-bore tube into C, and finally through a fourth into D. The connecting tubes being of small bore, the flow through them was non-turbulent, and the rate of discharge was accordingly directly proportional to the head, which thus corresponded perfectly with the number of atoms of a radio-active body. It was shown that the height of the liquid in B reached a maximum before A was empty, and that thenceforward the rate of fall of the level in B increased steadily until A was emptied. A similar state of affairs occurred with C. It was possible, Sir Ernest said, to supply fresh liquid to A so as to maintain the head there constant. In that case the level of the liquid in B and C ultimately would become steady, and the conditions then corresponded to a chain of radio-active bodies in the state of equilibrium. In this latter case exactly the same number of molecules left each one of the three tubes in every second of time, just as in the equilibrium condition of radium and its emanation equal numbers of atoms of each broke up in equal times.

To illustrate how rates of decay could be determined, Sir Ernest Rutherford passed a puff of air through a vessel containing a little actinium emanation and then into the Zeleny electroscope. The activity of this emanation fell, he said, to half value in 3·9 seconds, and the rapid slowing down of the oscillations of the gold leaf was readily observed. Repeating the experiment with the thorium emanation, of which the activity falls to half value in 54 seconds, he showed that the rate of decay was very visibly slower, and he further showed that by sending a current of air through the electroscope the emanation previously introduced there could be blown out, and the gold leaf brought to rest. He pointed out that in each case the puff of air sent into the electroscope, carried with it an almost infinitesimal quantity of the emanations. When bodies were exposed to these emanations, he proceeded, they became coated with radio-active matter, the result of the disintegration of the emanations. From the actinium emanation we could thus—see Fig. 11—collect actinium A. In this transformation the gas was transformed into a solid, which was deposited on any surface exposed to the emanation. There was nothing like enough of this deposit to produce a film on the surface, but owing to its radio-activity it was possible to determine its chemical properties as well with 10^{-14} grammes of the substance, as it would be a kilogramme. In the early stages of the study this had not been realised by objectors, who spoke derisively of what they dubbed "phantom chemistry." To show how readily the chemical properties of these infinitesimal quantities of radio-active matter could be determined, Professor Rutherford took a piece of platinum which had been exposed for some time to the actinium emanation. Cutting this up into three pieces, he first showed that the platinum was strongly radio-active, by bringing it near the Zeleny electroscope. The platinum, he said, had deposited on it a few atoms of actinium A, actinium B, and actinium C. Taking one of the pieces, he showed that after dipping it into hydrochloric acid, the greater part of the radio-activity was lost, the active body having been dissolved off by the acid. He next showed that by heating the platinum over a Bunsen burner the greater part of the deposit could be volatilised. In this operation the actinium B was, in fact, completely driven off, but some of the actinium C remained, as this body was more difficult to vaporise. He then dipped the third piece of platinum foil in water and showed that this had no effect on the activity, and then, taking a fourth piece, which had been prepared before the lecture and left for a long time in contact with chlorine gas, he showed that this was still active, but on washing it with water this activity disappeared, the chloride formed by the exposure to the gas being soluble in water. In this way it would be seen, he said, we could demonstrate the chemical properties of these substances, in spite of the excessively small amounts available.

He took next a small tube in which radium emanation had been stored for several years, so that the whole of the emanation had disappeared and the longer period elements alone left. Breaking this up, the polonium inside the tube was dissolved in acid, and on placing a copper plate in the liquid some of the polonium atoms were electrolytically deposited there, which he proved by showing that the plate was radio-active and would discharge an electroscope. Polonium could also be deposited on copper by passing a current through an electrolytic cell, where it came down on the cathode, which was thus rendered radio-active. Very little was deposited on the anode. In this way it was proved that polonium could be electro-deposited like any other metal. Polonium was, he continued, much more volatile than radium B and was, he showed, easily driven off from the copper by heat. In these experiments he was, he said, dealing with less than 10^{-14} grammes of the metal. Taking another piece of copper, which had been exposed to radium emanation and had an activity equivalent to that of 20 to 30 grammes of radium, he showed that this was extremely active, although, if the surface of the copper was divided up into squares, each side of which consisted of 50 atoms of copper, each of these squares would contain on the average only one atom of radium C, so that the layer was very far from forming a film even one atom thick.

Fig. 11.



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THE VARIABILITY OF SPECTRA.

THE problems of the amazing complexity and variability of spectra, which make the non-expert question the reliability of spectroscopic evidence, are not likely to find early solution. One begins to understand, however, that the complexity is only masked in the simple line spectra, on which Bunsen and Kirchhoff based spectrum analysis sixty years ago. That view was not expressly stated by Dr. T. R. Merton, F.R.S., Professor of Spectroscopy at Oxford, when delivering last week both the Bakerian lecture on "The Spectrum of Hydrogen," before the Royal Society, and a discourse on "The Variability of Spectra" at the Royal Institution. But we may draw that conclusion. We first notice the more general discourse.

The radiation emitted by an element in the state of a luminous gas varies with the experimental conditions, the mode of excitation and also the presence of other elements. To illustrate this Professor Merton first made use of a Bunsen burner so arranged (Fig. 1) that a spray of the substance is introduced into the flame from below. He replaced the tray of the diagram by a flask containing the solution to be examined to which he added hydrochloric acid and a small piece of magnesium; hydrogen was evolved, and this gas carried a spray upward into the flame. Strontium chloride thus dealt with gave a crimson flame, in the spectrum of which could be distinguished not only the lines of the metal, but also the bands of the chloride and of the oxide—in addition, of course, to the hydrogen lines. When a similar experiment was made with copper nitrate and nitric acid, the flame was green; when a little cotton wool, soaked with chloroform (trichloromethane $CH.Cl_3$) was interposed between the top of the flask and the bottom of the burner, the flame

assumed the blue colour of the copper chloride—the blue colour which we see, the lecturer stated, when a little common salt NaCl is thrown on a coal fire, because the coal contains traces of copper. In this way minute impurities could often be detected. But flame reactions were in themselves complex, and spectra were hence better studied by passing the electric discharge through pure gases, generally at low pressures in vacuum bulbs. Such bulbs were frequently fairly wide at the electrode ends and constricted in the central portion.

Nitrogen thus examined showed, with the uncondensed discharge, a pink glow and a positive band spectrum, in the capillary portion, with a bluish glow and a negative band spectrum near the cathode; this latter constituted an important part of the aurora spectrum. When a condenser and a small spark gap were switched in, the current density became momentarily much higher at each discharge (the total intensity remaining unchanged), more nitrogen molecules were broken up, successive electrons were probably removed from the atoms as the intensity was further raised, and the discharge brightened up and changed in colour and in its spectrum. The effects were especially marked

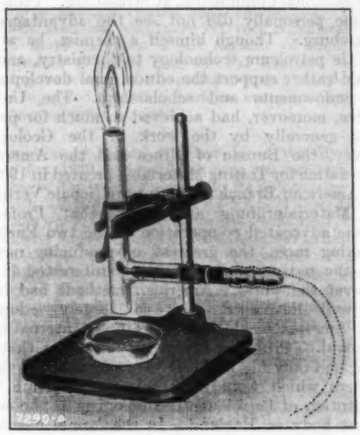


FIG 1.

in the capillary portion of the bulb, where the current density was relatively high, and they were also produced locally when a portion of the bulb was held in a magnetic field. Under different conditions of excitement the carbon arc showed at least six band spectra, partly due to compounds of carbon with hydrogen, oxygen and nitrogen, and the bands narrowed more and more as the discharge was intensified, until they were quite sharp, as in the carbon lines in the hottest stars of the Wolf-Rayet type.

Most of these variations, Dr. Merton continued, could reasonably be accounted for; but it was very difficult to explain some peculiarities in the spectra even of hydrogen, the atom of which we believed to consist merely of a nucleus and one electron. Hydrogen had two (or three) spectra. The first consisted of the well-known lines Hα, β, γ . . . (in the red, yellow, green, blue, &c.) of the Balmer series, which were seen in almost all celestial spectra and also in laboratory tubes, because traces of hydrogen were difficult to exclude. The "secondary" spectrum was crowded with lines (exceeding 1,200) all over, and this latter spectrum—not the single Balmer lines—was characteristic of pure hydrogen and never observed so far in stars. The discharge through pure hydrogen was of a beautiful blue colour; impurities changed the colour into pink, and a trace of water vapour was sufficient to extinguish most of the secondary lines, except some in the red and yellow. This can be seen in the upper spectrum of Fig. 2, in which the yellow Balmer line is less distinct than the others; the lower spectrum is the secondary.

Dr. Merton exemplified this result by introducing pure hydrogen into a discharge bulb; this was done by heating by a hydrogen flame a palladium tube, previously charged with hydrogen; palladium was permeable only to hydrogen. The discharge was blue, whilst an ordinary hydrogen bulb, impure probably with a little vapour of water and mercury, gave a pink discharge. The change in colour was due to the fact that the impurities affected different lines to a different degree, and that showed that the lines could not all have the same genesis. We shall revert to this point. The ordinary vacuum bulbs contained the gas at the low pressure of a few millimetres of mercury. When the gas pressure was raised to 50 mm. and more, the numerous lines of the secondary spectrum almost coalesced, finally forming the third continuous spectrum of hydrogen, while the gap between the ultraviolet and the Schumann rays was bridged over.

From the theoretical point of view the spectrum of the inert gas helium was second in importance only to that of hydrogen. The helium spectrum was seen in the chromosphere of the sun (where helium was discovered), and in many stars, and the relative intensities of the helium lines varied there as much as they did in the laboratory. There were at least three helium spectra, and six series of lines

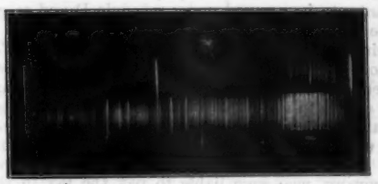


FIG. 2.

FIG. 3.

could be distinguished, three known as the helium series and three as the parhelium series. The parhelium series predominated at low pressures, and since the green was strongest in the parhelium, and the yellow in the helium, the colour changed from yellow to green as the gas pressure was reduced. Dr. Merton illustrated this, and also the influence of impurities, in striking ways. A helium bulb through which the discharge passed looked green; when the lower end of the bulb was immersed in liquid air, the colour in that cold portion, in which the helium was more concentrated, turned yellow. Another bulb was filled with helium by heating a tube containing thorianite, connected to the bulb. The gases thus introduced consisted of helium, nitrogen, carbon dioxide, water vapour, &c.; most of these gases, except helium, were absorbed by a charcoal tube joined to the discharge bulb, and as this absorption proceeded, the colour of the discharge bulb assumed more and more the yellow tint of the helium.

The influence of helium on the hydrogen spectrum was exemplified by Fig. 3. Spectrum B (the lower) was that of pure hydrogen; the upper spectrum A that of a mixture of helium with very little hydrogen; yet there was only one helium line D_3 in the spectrum A, and the relative intensities of the hydrogen lines were differently affected. A trace of carbon altered the helium spectrum in a similar way; those intensified bands were strong in the spectra of comet tails. One of the band spectra of helium corresponded to the "secondary" spectrum of hydrogen, because it only appeared in very pure helium. The occurrence of this spectrum was very remarkable. The secondary hydrogen spectrum was—as we shall see—ascribed to the hydrogen molecule (not to the atom), and helium was not supposed to form molecules at all. But there might be temporary associations not strictly of molecular character in the chemical sense. Professor Fowler had shown that the arrangement of the head of the bands in this helium spectrum resembled that found in series attributed to atoms. Passing powerful condenser discharges through helium Fowler observed that the spectrum assumed the character of a spark spectrum, and he discovered two series, known in stellar nebulæ and in early types of stars; Fig. 4 shows in the upper part this spectrum (thick lines) and the ordinary helium spectrum in the lower portion.

The energy required to produce spark spectra, Dr. Merton proceeded, varied with the nature of the gas and was, for elements of the same chemical group, generally the smaller, the greater the atomic weight. This was demonstrated by coupling bulbs of helium, neon, argon (atomic weights 4, 20, 40) in series. With the uncondensed discharge (mild excitation) the helium bulb alone was fairly brilliant; the condensed spark discharge brought the orange neon and the blue argon colour (at first pinkish) out splendidly. By the aid of coloured slides Dr. Merton proved that the colour changes were, as in other cases, due to the relative intensity changes of various lines and to their broadening to different degrees. Lines were broadened and resolved by

FIG. 4.

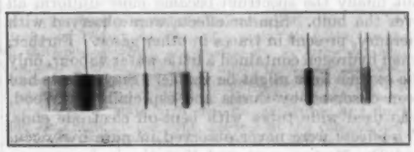


FIG. 5.

the Stark effect of a local electric field, similarly as a strong magnetic field widened and resolved the lines (Zeeman effect). Generally the more refrangible rays were more enhanced by increased electric energy, but that varied with the series. Whilst now pure hydrogen showed a much stronger Stark effect than helium, the hydrogen lines were little broadened in mixtures with helium (upper spectrum of Fig. 5; the lower spectrum is that of hydrogen). That proved that one gas might exert a specific selective influence upon another gas present, not of a chemical kind; for helium was chemically inert. The nature of neighbouring atoms would alter the electric field and thus change the conditions of the discharge and of the radiation.

In his Bakerian lecture, to which we pass, Dr. Merton, who was associated with Mr. S. Barratt, dealt mainly with the secondary hydrogen spectrum, characteristic of pure hydrogen and of feeble discharges, and with attempts to classify the enormous number of lines for the purpose of tracing their genesis. In such research the utmost purity and accuracy of measurement, down to 0·001 Angström unit, A.U., were essential. Dr. Merton pointed out a possible source of error in comparative wavelength measurements of overlapping asymmetrical bands. In determining line intensities, Dr. Merton and Professor Nicholson made use of a double glass wedge, consisting of a colour-tinted glass and a colourless glass cemented together so as to form a plane-parallel plate. The plate was mounted in front of the spectrograph slit, and the photographed lines then looked like arrow heads, the higher the more intense the line. When the positive was enlarged through a ruled process screen, the image was made up of a number of dots, and the length of the line could be determined by pricking out the last visible dots.

Fulcher had attempted to classify about 100 lines of the secondary hydrogen spectrum with the aid of the Zeeman and Stark effects. That was only

possible for strong lines, and the two classifications did not agree with one another or with differentiations obtained by altering the discharge and gas pressure conditions. Lines might be due to oscillation of the atoms and to molecular oscillations. The width of a line admitted of drawing conclusions as to the mass of the vibrating particle. Fabry and Buisson determined this width by interference methods; Dr. Merton described their own new method. The band they obtained by the wedge method would be a peaked curve wider at the base than at the top, and they attempted to determine the base or width of a rectangle equal in area to the band and of the same height. If the band were photographed through screens of different absorbing power, the equivalent width would change with the degree of absorption; instead of using a screen, they took photographs of different order spectra through an échelon grating. They had further to know the temperature at the respective spot of the discharge; that they determined roughly by fixing specks of organic compounds on the walls of the bulb (*e.g.*, cinnamonic acid, melting-point 456 deg. C.) and allowing for heat loss by radiation. In that way they found, *e.g.*, a band width of 0·032 A.U., which was in good agreement with the calculation for a vibrating molecule; the atom should give a width of 0·046 A.U. The conclusion was that the secondary hydrogen spectrum was due to the molecule.

There was, further, evidence that the high-density discharge effected a certain separation of the constituent gases in mixtures, *e.g.*, of helium and hydrogen. In such mixtures containing little hydrogen the hydrogen lines were only seen at the bulb ends near the electrodes; when the condenser was cut out, they remained visible there for a time, but finally the spectrum became more uniform all over the bulb. Similar effects were observed with mercury, present in traces in other gases. Further, when hydrogen contained a little water vapour, only the oxygen lines might be visible. Such effects had been observed by Curtis and especially by Wood, who used wide tubes with bent-off electrode ends. The effects were never observed in pure hydrogen, and Dr. Merton suggested that the hydrogen was really transferred by the electric discharge, and that its lines did not show in parts, from which the hydrogen had been removed, until it had had time to diffuse back. Such gas separations might take place in stellar nebulæ and new stars. Dr. Merton referred to other evidence of specific influences of neighbouring atoms on the spectrum lines, which indeed had long since been observed, though not so interpreted. But the discussion by Sir Arthur Schuster, Professors Nicholson and Newall and others indicated that we were not yet able definitely to assign lines to the vibrations of molecules or of neutral or ionised atoms.

NOTES.

RAILWAY PROBLEMS IN AUSTRALIA AND CHINA.

THE railway problems of countries so diverse in character as Australia and China would appear to be rather difficult to discuss with any continuity of argument or criticism. China with its huge area settled for centuries by teeming millions, is a great contrast to Australia with its one or two inhabitants to the square mile, and comparatively speaking all recent comers. That Mr. T. R. Johnson brought the two subjects together in a paper he read on Monday last before the Institute of Transport, is due, not we take it to any fact that the problems of these countries are related or similar, but to the fact that the author's official connection with both has given him first hand experience of each. Mr. Johnson's contribution does not, in the case of Australia, carry the matter much further than has been done on previous occasions, this part of his paper dealing largely with the settlement of the gauge question, the latest position of which we summarised in a leading article on page 80 *ante*. With regard to China, Mr. Johnson points out that the country averages as far as can be ascertained about 200 inhabitants to the square mile, and with an area of about 4,250,000 sq. miles has at present about 6,800 miles of railway. Owing to financial stringency, in addition to Government railways, concessions have been granted in the past to financial syndicates of various nationalities—British, German, French and Belgian—and these had each built to the practice of their respective national schools of railway engineering. The result was now that China, although no gauge problem worth speaking of had to be settled, still was faced with the desirability of standardising in other directions. The systematisation of accounts had now been brought about, and agreement on other matters as, for instance, a standard specification for steel bridges. Among new lines the most important proposal is that of the completion of the Pekin-Canton Railway, in which there is a gap of about 250 miles. It is hoped that this will be commenced shortly. Another promising development is a proposal to extend railway communication into the rich province of Szechnan from Hankow.

INCOME TAX—THE THREE YEARS' AVERAGE.

On March 13 the House of Lords gave judgment in an income tax case, the Great Western Railway Company *v.* G. W. Bater, Surveyor of Taxes, which seems likely to have the most far-reaching effects and to enable many employees of limited companies to be assessed under schedule D and so get the benefit of the three years' average instead of being assessed as hitherto under schedule E. The short question in the case was whether the assessment for the purpose of income tax on the salary of a clerk in the employment of the Great Western Railway Company should be under schedule E or under schedule D. The surveyor contended that it should be under schedule E. The railway company, who were liable to pay the tax in the first place, contended that it should be under schedule D. On the surveyor's contention the clerk would not get the benefit of the three years' average; on the railway company's he would. The House of Lords laid it down in the clearest terms that the clerk's salary could not be assessed under schedule E unless he held a public office or a public employment of profit; and although they did not say what was a public office or a public employment of profit, they decided by a majority of four to one that the clerk had not a public office or a public employment of profit, and that the assessment should not be under schedule E. We understand that hitherto the practice of the surveyors of taxes has been to assess under schedule E persons holding offices or employments of profit under limited companies without considering whether the office or employment of profit was of a public nature or not, but the effect of the judgment seems to be that in future they will require to discriminate between offices or employments of profit which can be said to be public, and those which cannot be said to be public. In all cases, therefore, in which limited companies are asked to give returns under schedule E of the salaries of their employees, they should consider most carefully which of them should be treated as holding offices of a public nature and assessable under schedule E, and which should be regarded as assessable under schedule D in respect that their offices are not public; and in considering which offices are public and which are not, the officials of the companies should not yield too readily to the blandishments or the arguments of the surveyors.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

Entering upon the second year of his presidency Professor J. S. S. Brame, F.I.C., addressed the annual meeting of the Institution of Petroleum Technologists, held on the 14th inst., on national and international aspirations for unification and standardisation in petroleum technology. At the early international conferences of petroleum industrials and scientists meeting in connection with Paris exhibitions, little was achieved. The Bucharest Conference of 1907 appointed 17 experts to deal with analytical and testing problems, but that number was too small. The proposal for national sections came from Berlin in 1908, and the International Chemical Congress, held in London in 1909, had for the first time a special Petroleum Section. An International Commission under the presidency of Prof. Carl Engler was established at Karlsruhe, to the Technical High School of which petroleum technologists congregated from all parts of the world. The International Petroleum Congress of Vienna, in 1912, was attended by almost all interested countries, including the United States, Russia alone not being officially represented. It was agreed that the nomenclature should have a scientific basis with due regard, however, to commercial uses. Various problems were assigned to various committees; storage, transport and fire insurance were also discussed, but France and the United States did not approve of dealing with these questions, and the Government representatives were on the whole reluctant to bind themselves. The next conference, originally projected for 1913, was to meet in London in spring, 1914, but Rumania interposed an invitation to Bucharest, and the preparations were so much delayed thereby that the London conference was again postponed. Then war intervened. Meanwhile an International Petroleum Institute, to deal also with statistics and literature, had been suggested, the initiation coming from Germany, though not for Germany and not from Karlsruhe; Rumania again proposed Bucharest as the seat of that Institute. After the war the Société Industrielle de Chimie proposed to resuscitate the International Commission, at Strassburg. Professor Brame personally did not see the advantages of Strassburg. Though himself a chemist, he would not tie petroleum technology to chemistry, and he would rather support the educational development by endowments and scholarships. The United States, moreover, had achieved so much for petroleum generally by the work of the Geological Survey, the Bureau of Mines and the American Association for Testing Materials—created in 1902 as the American Branch of the Internationale Verband für Materialprüfung at Vienna—that Professor Brame advocated co-operation of the two English-speaking races, the greatest oil-producing nation and the nation most extensively interested in oil all over the world. American methods had been so well developed and so largely adopted that America would hardly wait for international approval. Professor Brame made it clear that he expressed only his personal views on some of these matters which would naturally come before the Institution of Petroleum Technologists as the competent body in England. In the formal meeting, which had preceded the general meeting, the Institution had modified its by-laws in order better to be able to widen the scope of its national and international aims.

INDUSTRIAL NOTES.

The subject of the Engineering Trade Dispute is dealt with in our leading article on page 329.

In regard to the employers' proposal for the withdrawal in two instalments of the 26*s.* 6*d.* weekly war bonus in the shipbuilding trades, conferences have been held since our last report on page 304 *ante*. As a result of these the men have accepted the principle of a reduction and have shown their willingness to negotiate a settlement. They have, however, rejected the proposal of having the withdrawal made in two instalments of 16*s.* 6*d.* now and the balance of 10*s.* later, and want the cut to be made by smaller amounts at a time. This matter of the shipbuilding trades' bonus, which is still being considered by the owners and unions directly concerned, was at first distinct from that of the engineers', but the lock-out in the engineering trades, which came about through difficulties mainly with the members of the Amalgamated Engineering Union, threatens to involve other unions and also to complicate the situation in regard to the shipbuilding trades proper.

The pass which the industries of this country have now reached is further illustrated by an occurrence in the timber milling trade of Hull and its vicinity. Owing to slackness two timber mills had of late been working alternate weeks only. An urgent order having been received, the owners decided last week to run a machine in the closed mill, and two machinists were requested to operate this. The two men refused to work, alleging that "under the rules of the Amalgamated Society of Woodcutting Machinists, where a mill is on short time the whole of the workers shall work the shorter hours." In this particular instance, there was only enough work for the two machinists in question; they having refused to carry it out, the order could not be executed. This is another case of

freedom of management pure and simple, occurring, like similar cases in the engineering trades, at a time when it is necessary as never it has been before that every effort should be made by everyone to work to the utmost capacity. During the last few days, trade union officials have issued manifestoes stating that the employers are making war on the unions and want to smash them. The employers deny this, adding that they simply want, in the interests of the country, to control managerial functions in their establishments. Any unbiased person, in view of the Hull instance above reported, and other instances in the engineering trades, cannot fail to recognise that the "rules" of the unions require amending.

The secretary of the London Iron and Steel Exchange, Limited, states that the crisis in the engineering industry has reflected upon the home demand for foundry pig-iron, since the stoppage of the engineering shops will stop the call for castings. He adds that the decision of the London Metal Exchange and the Glasgow pig-iron trade to re-establish a market in pig-iron warrants in London and Glasgow has aroused interest in the business circles; but it will be a long time before dealings can assume practical importance. The producers generally appear to be opposed to re-opening the markets; but several iron makers regard it with less disfavour. In the finished material department the engineers dispute has been sharply felt, and the improvement in home trade buying, that promised to develop on satisfactory lines, has been checked. The overseas demand has also fallen off very considerably although there has been a fair amount of inquiry. The suspension of orders from the Far East has been a conspicuous feature of the position during the week, and it is suggested that the Americans are again offering at cut rates in those markets.

The motion in regard to Part II of the Mining Industry Act, 1920, referred to on page 259 *ante*, asking the House of Commons to agree to its not ceasing to have effect, has been introduced by Mr. S. Walsh. He stated that when the Act came before Parliament, the Labour Party opposed Part II. Now there was a change in their attitude and they wished it retained. After several members had spoken, Mr. Bridgeman, the Secretary of Mines, said the history of Part II was a deplorable one on both sides. The attitude which the Government must take up had to be one of strict neutrality. It was of little use setting up pit and district committees except with the hearty co-operation of both sides. The Government having given eighteen months to the two parties to come to an arrangement under Part II, and no agreement having been reached, the best hope was to rely upon their coming together under a voluntary arrangement similar to that which was made in other industries. The motion was defeated by 141 to 99 votes.

On the same day, and in answer to a question, Mr. Bridgeman said he had no information as to the amount of royalties, rents and wayleaves in Northumberland in 1914. In the quarter ended September, 1921, the latest period for which particulars were available, they amounted to 10½*d.* per ton. Ship freights from Blyth to London in June, 1914, were 2*s.* 9*d.* to 3*s.* per ton, as compared with 5*s.* to 5*s.* 6*d.* per ton now. The railway rate on coal from collieries in the neighbourhood of Newcastle to London was 9*s.* 6*d.* per ton in June, 1914; at present it was 13*s.* 6*d.* per ton. In 1914, Mr. Bridgeman added, the average cost of raising a ton of coal was 8*s.* 9½*d.*, of which 2*s.* 1½*d.* represented costs other than wages and royalties, whilst in the quarter ending September 30, 1921, the corresponding figures were 24*s.* 1*d.* and 6*s.* 7*d.* respectively.

At a recent conference held in London of the Transport Workers' Federation, when the new wage scheme put forward by the Port employers was considered, the wage reduction of 1*s.* per day was accepted by an overwhelming majority. This brings wages down to 12*s.* per day in the large ports and to 11*s.* per day in the smaller.

In the matter of the Danish labour trouble, the Employers' Union has sent a communication to the trade unions defining several points and emphasising the inadequacy in many respects—more especially as regards hours and overtime pay—of the mediator's proposal, from their point of view, but adding that the masters nevertheless accepted it. As to the relative position of wages, &c., before the war and now, the employers state the average weekly wage for skilled labour in 1914 was 35 kronen 31 öre, and if this had been increased in the same proportion as the rise in the index number it would now have been 74 kronen 86 öre. The average wage for skilled labour in September, 1921, however, was 98 kronen 40 öre, which, with the 15 per cent. reduction comes out at 83 kronen 64 öre, or 8 kronen 78 öre more than if paid according to index number. For unskilled labour the figures are still more favourable for the men. The average weekly wage in 1914 was 26 kronen 21 öre; according to the index number it should now be 55 kronen 57 öre, but the average wage for September, 1921, was 80 kronen 64 öre; deduct the 15 per cent. from this figure, and the wage comes out at 68 kronen 14 öre, or 12 kronen 57 öre more than it would have been according to the index number. For female labour the average wage was 17 kronen 5 öre in 1914, the index number would raise this to 36 kronen 15 öre; the weekly wage in September, 1921, was 50 kronen 88 öre, which, reduced by 15 per cent. comes out at 43 kronen 25 öre, or 7 kronen 10 öre above a wage according to index number. This means an average for all kinds of labour of 8 kronen 5 öre above the wage fixed according to the actual rise in the price of commodities. Further, it must be borne in mind, that the average hours per day in 1914 were 9·5, whereas it is now 8 hours, so the mediator's proposal means an extra weekly wage of 8 kronen 5 öre for less work. The men will not accept the 15 per cent. reduction on the September, 1921, wage, but only 10½ per cent., as per fall in the index number, but not the remaining 4½ per cent. which represents the fall in industrial markets, &c.; the lock-out has cost the men the difference. Negotiations have been resumed. (1 kronen = 100 öre = about 1*s.* 2*d.*)

PNEUMATIC EQUIPMENT FOR CONTRACTORS' WORK.

In order to secure contracts and maintain employment as far as possible under the conditions existing at the present time, it is more than usually important to employ the best available means for economising labour and expediting work. This feature is well exemplified in connection with some work now being carried out for the Post Office by Messrs. John Mowlem and Co., Limited, Ebury Bridge-road, S.W.1, who are well known for the use of modern appliances to an extent which is distinctly above the average. In the particular work we are now referring to, compressed air is being employed for operations usually performed by manual labour, but before briefly describing the plant and equipment, as we propose to do, it is necessary to indicate the character and purpose of the work.

As some of our readers are probably aware, a small pneumatic railway was constructed some sixty years ago for the purpose of conveying mails from St. Martin's-le-Grand to Euston Station. The railway ran in an underground tube, measuring 4 ft. 6 in. wide and 4 ft. high internally, constructed partly of brickwork and partly of cast iron. The lower portion of the tube was rectangular and the upper portion semi-circular in section, and the tube was situated some 10 ft. or 12 ft. below the surface. The railway has not been used for many years, but the tube is apparently still in good condition, so that it has been decided to make use of that part of it which runs under Holborn as a duct for telephone cables. To give access to the tube for this purpose manholes are being constructed at intervals along the route, and it is for cutting through the concrete road foundations, excavating the earth and cutting openings in the walls of the tube, that the pneumatic appliances are being employed by Messrs. Mowlem.

The main item in the equipment is a portable air compressor set supplied by Messrs. Lacy-Hulbert and Co. (1921), Limited, Boreas Works, Beddington, Croydon. This consists of a 40 h.p. 4-cylinder Dorman engine driving a two-cylinder vertical single-stage air compressor through cut spur gearing giving a 3 to 1 reduction. The engine, which works with paraffin and is started with petrol, runs at about 900 r.p.m. and is cooled by a radiator and fan, while tank cooling is employed for the air compressor. The cylinders of the latter are each 275 mm. (10·83 in.) in diameter and the piston stroke is 250 mm. (9·84 in.). The capacity of the compressor, running at its normal speed of 300 r.p.m., is 140 cub. ft. of free air per minute compressed to 100 lb. per square inch, which is sufficient for the operation of four of the percussion-type drills used for cutting concrete. A welded steel air receiver is provided, and the whole plant is carried on a channel-bar frame mounted on four cast-steel rubber-tyred road wheels. The two front wheels are fitted to a swivelling carriage having a draw hook which can be used for moving the plant from place to place by means of a motor lorry. A sheet steel roof is fixed over the engine and compressor, and the whole of the machinery can be completely enclosed by steel plate side covers when not in use.

As above mentioned, percussion-type drills are employed for cutting through concrete, the one we saw in use when inspecting the work on Monday last being a pick hammer supplied by Messrs. Lacy-Hulbert. The tool, which combines some of the features of both a rock drill and a riveting hammer, weighs about 40 lb., and is held up to the work by hand, the cutting being effected by a pointed bit of octagonal steel. We were informed that the time required to break up a cubic foot of 5 to 1 concrete was about 40 secs., and that two men could usually be kept employed in shovelling away the spoil produced by one tool. Another tool in use for excavating earth, clay, &c., was a pneumatic spade, about the size of a man's hand, and forming an attachment to an Ingersoll long-stroke hammer. With this tool the operator can cut through any comparatively soft material with great rapidity and with little or no effort. Pneumatic rotary drills, we understand, will be employed for cutting through the cast-iron parts of the tube, but these were not in use at the time of our visit.

We would remark, in conclusion, that while the work to which we have referred is by no means the first for which pneumatic tools have been employed in connection with excavation, the application is of interest on account of the character of the work, and the completeness of the equipment. Another noteworthy point is that the compressing plant is of British manufacture.

LARGE INTERNAL COMBUSTION CYLINDERS.

To the Editor of Engineering.

Sir,—About a year or so ago, in his address to the British Association, Sir Charles Parsons stated that the British Association research on gaseous explosions had saved British engineers many thousands of pounds by showing that the intensity of radiation to the walls of an explosion cylinder increased as the size of the vessel was increased, and that this fact explained why large gas-engine cylinders were liable to failure in service.

In your last issue Professor David has contributed a most instructive article on gaseous explosions, concluding as follows: "The reason for the unreliability of the large gas engine is thus clearly seen, and the physical impossibility of designing very large engines working upon ordinary cycles will be obvious unless steps are taken to secure lower gas temperatures in the working cylinder." In what follows I wish to maintain that the size of cylinders which are practically feasible can never be limited by the intensity of heat flow per unit of area (hereinafter called the heat flux).

Professor David realises, of course, that the great wall thicknesses which are customary in large engines are a source of trouble quite apart from any increase in the heat flux which may attend the use of large cylinder dimensions. Taking his own comparison between a 12-in. and a 60-in. cylinder, he states that the flux would be about 50 per cent. greater in the case of the latter. What is perhaps more serious still is the fact that with ordinary methods of construction the walls of the large cylinder would be four or five times as thick as those of the small one.

There is, however, no very good reason why the ordinary methods of construction should continue to be practised. The heat flux through the walls of an aero cylinder is certainly very much higher than that through the walls of a 60-in. gas engine cylinder working at a moderate piston speed. The aero cylinder survives because its walls are thin.

Evidently the right way to design a very large gas or oil engine cylinder for a high heat flux is to provide thin walls (separating gas and water) supported externally by any adequate means, several of which will suggest themselves to any designer. The design of large Diesel engines is already tending in this direction. Examples of this sort of thing are to be found in the Still engine illustrated in your issue of March 3, the Blohm and Voss double-acting two-stroke engine, the later German submarine engine, &c.

In most Diesel engines the cylinder liner is free to expand relatively to the jacket, and cracking is practically unknown (apart from piston seizure) even with liners 2½ in. thick in highly rated two-stroke engines. The heat stress troubles are confined to the cylinder covers and pistons, and these troubles are being overcome by providing thin walls supported by stronger members to carry the pressure loading.

When two-stroke oil engines of 50 in. bore or so are undertaken for the propulsion of Atlantic liners it will probably be necessary to carry out similar principles in connection with the cylinder liners. In view of these considerations I am inclined to believe that the alleged physical impossibility of constructing very large highly-rated, reliable internal-combustion engine cylinders is fallacious. There are no doubt difficulties just as there were difficulties in the development of the large steam turbine, but I think they will be overcome without resorting to lower gas temperatures.

It is not difficult to explain the failures of many large gas engine cylinders. In many cases the liner and jacket were combined in one casting accommodating all the valves, and the shapes adopted for the combustion chamber were unfavourable for free expansion. Also excessive metal thicknesses were used which could be avoided by suitable subdivision of the casting.

Another difficulty remains with large slow-running engines, and that is the cyclic fluctuation of temperature of the inner face of the cylinder wall. In high-speed engines this fluctuation has been shown to be negligible, but in engines making, say, 60 r.p.m. this may not be the case perhaps. This difficulty also, I think, is not insuperable.

I should be glad to know if the increased heat flux to which large cylinders are said to be subject is reflected in the jacket loss figures expressed as a fraction of the total heat supplied. Personally I have not been able

to trace any relation between the cylinder dimension and the jacket loss in the figures which I have been able to examine. On the face of it the jacket loss would appear to depend not only on the relation of heat flux to temperature and linear size of vessel, but also on the influence of linear size on the time distribution of temperature throughout the cycle. It would be interesting to hear the views of the manufacturers of large cylinder gas engines.

Whilst differing from Professor David with respect to the point referred to above I should like to express appreciation of the work he has done towards the elucidation of the different problems of the distribution of heat in internal-combustion cylinders, and also of the lucidity of his article referred to above.

Yours faithfully,
H. F. P. PURDAY,

76, Sarum Hill, Basingstoke, March 11, 1922.

STRESSES IN THE FRAMES OF RUBBER MACHINERY.

TO THE EDITOR OF ENGINEERING.

SIR,—I should be glad if you or any of your numerous contributors could give me any information regarding the stresses encountered in the frames of machines for the macerating, washing and mixing of rubber.

After a lengthy search for any information relating to this, I have not been able to find any data. It is obvious, of course that the pressure will vary according to roller size and length, and also upon the consistency of the material being treated, but if any of your correspondents could give approximate figures for pressure per square inch, I should be greatly obliged.

Yours faithfully,
"ESTATE."

"BALL AND ROLLER BEARINGS: THEIR DESIGN AND PERFORMANCE."

TO THE EDITOR OF ENGINEERING.

SIR,—The interesting point raised by Mr. Heathcote in your issue of February 24, page 230, in connection with the thrust capacity of ball bearings, seems to call for further comment.

I stated in the lecture under discussion that the thrust coefficient with the single-row type was greater than that of most sizes of the double-row type, which admission meets the greater part of Mr. Heathcote's contention, but I am doubtful as to the validity of his claim to a coefficient of 4 if the single-row bearing he has in mind is of the filling slot type. I have dealt with this fully in the lecture already, but in turning to the Proceedings of the Institute of Automobile Engineers, 1921, page 591, to which Mr. Heathcote refers me, I find he figures out that a single-row bearing with a listed radial capacity of 1,590 lb. at a certain speed can take a thrust load of 2,200 lb. On comparing this with the test figures he gives on page 659, it can scarcely be claimed that theory and practice are in agreement. As a matter of fact, if the axial portion of the load be multiplied by the factor of 4 and added to the radial load it will be found in each case to add up to just about 2,000 lb., which is only a slight overload over the listed radial capacity of 1,500 lb. Is Mr. Heathcote satisfied that the life quoted by him in these tests warrants him adopting the factor 4 for general practice?

Many types of double-row self-aligning construction bearings give equal performance in daily service, but I take the opportunity of emphasising again the necessity of not over-rating the capability of journal ball bearings to act as double-purpose units.

Yours faithfully,
A. MACAULAY.

The Skefko Ball Bearing Company, Limited, Head Office and Works, Luton, March 6, 1922.

BURNING LIGNITE ON CHAIN-GRATE STOKERS.

TO THE EDITOR OF ENGINEERING.

SIR,—I have been much interested in the illustration of the setting of a watertube boiler for burning lignite, which appears on page 257 of your issue of March 3. Quite apart from the danger of bringing hot gases directly into contact with the fuel in the hopper, with the risk of the heated fuel igniting, especially when the boiler is shut down, there seem to be several very practical objections to the design. The gases, on finally leaving the boiler have to pass through absurdly small holes in the side walls to get away to the flue. This would seriously interfere with the draught, and, furthermore, taking the gases out at the side of the setting would apparently compel all boilers to be set singly, with a considerable increase in cost. The exit flues coming between the settings would occupy a lot of valuable room, and involve unnecessarily long steam mains, feed pipes, bunkers and boiler-house generally. It is also to be noted that the water gauges are at the back end of the boiler drums. Other matters for criticism will rise to the minds of all engineers conversant with the practical operation of boilers.

The trouble in burning lignite on a chain grate is due to the high moisture content of the fuel. In an ordinary setting, such as one would use for bituminous coal, the lignite gets some considerable way along the grate before it begins to burn at all. While it is travelling this distance, its moisture is being evaporated. The evaporation cools the arch and combustion starts progressively later, until the fire goes out, or goes over the dumping bars. A mixture of bituminous coal and lignite can be burnt, but it is troublesome to get and keep the mixture right. Several years ago, as the outcome of experiments carried out at the University of Alberta, in Edmonton, Canada, a setting was devised which has proved highly satisfactory and enables even the worst kind of the local lignite stacks to be burnt without difficulty on a chain grate stoker with natural or induced draught. The front arch is made very short, and beyond it there is another larger and higher arch set at an angle so as to radiate the heat on to the incoming coal. Behind this arch is a space about 8 in. wide, separating the arch from the bridge wall. The evaporated moisture presumably escapes at the end of the first short arch and does not cool the main inclined arch which does the work.

Chain-grate settings of the type in question are now largely used in the West of Canada, and they burn coal which was utterly unburnable with the ordinary settings. Experience has shown that, so long as the main principles are adhered to, the proportions and positions of the arches may be modified to a reasonable extent. Engineers who are interested in the burning of lignite on chain grate stokers should find out what is being done with the Alberta lignite stacks, and I have no doubt that Professor C. A. Robb, of the Engineering Department of the Alberta University, or Mr. James F. McCall, the superintendent and chief engineer of the Calgary Power Station, would be pleased to give all information possible to any responsible inquirer. An actual example of a boiler setting, designed by Mr. McCall to burn lignite slack, is shown in the accompanying figures. It must be remembered that the arrangement represents a modification of a standard setting, a fact which accounts for the long "Dutch Oven" at the front. In an entirely new installation it is probable that the boiler would have been set higher, the grate put further in and the reverberating arch raised at its front end. Nevertheless, the arrangement shown was, the writer believes, quite satisfactory.

Yours faithfully,
M.E.I.C.

CHAIN-GRATE STOKERS FOR BURNING LIGNITE.

Fig. 1.

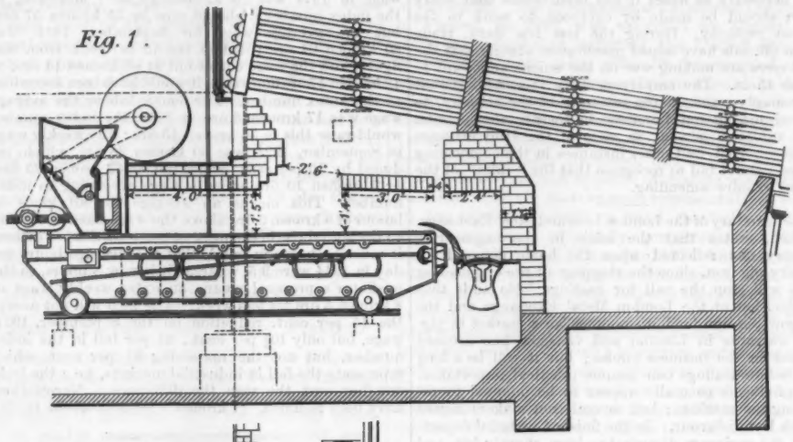


Fig. 2. OUTSIDE WALL SHOWING POSITION OF DOOR

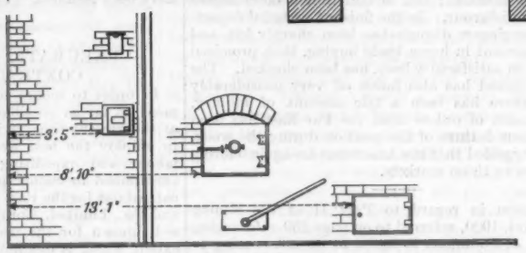
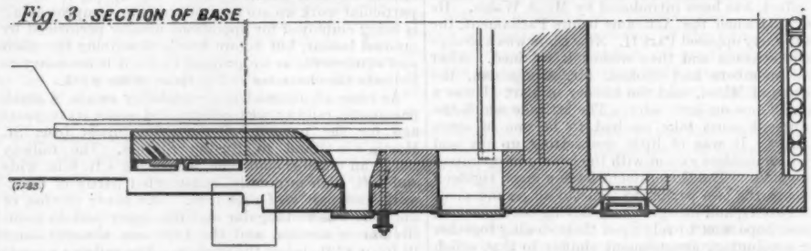


Fig. 3. SECTION OF BASE.



SUSPENSION BRIDGE FOR THE ARGENTINE REPUBLIC.—A despatch has been received from the Commercial Secretary to H.M. Legation at Buenos Aires, transmitting a copy of the specifications for a suspension bridge, with conditions of tender, &c., and a set of blue prints which may be examined at the Department of Overseas Trade, on application to Mr. Dempster, of the Engineering Section (Room 50A), until the 31st inst., after which date they will be available for loan to firms in the provinces who may be unable to arrange for their inspection in London. The tenders are to be presented on June 19, 1922.

SMALL OIL ENGINES IN HOLLAND.—As an indication of the popularity of this type of engine in the Netherlands, the record of the number of ships built during the year 1921 in that country is conclusive, says *Motorship*, New York, which adds that 102 oil-engine installations are recorded, the total horse-power being 3,929, so that the average installation works out at about 38 h.p. On January 1, 1922, 60 boats were under construction having close to 10,000 h.p. American manufacturers of oil engines of this power should take note of this record, says our American contemporary, as there is an even larger field in the United States of America for such motors.

PERSONAL.—The Spearing Boiler Company, Limited, and Messrs. Tinkers, Limited, Daisyfield Boiler Works, Hyde, Manchester, have come to an arrangement under which the Spearing Boiler Company acquire the controlling interest in Messrs. Tinkers'. The Spearing water-tube boiler will in future be made at the works of Messrs. Tinkers, where it is proposed to carry out large extensions to cope with the rapidly-growing demand. Mr. Spearing will join the board of Tinkers, Limited, as chairman, and Mr. Frank Tinker will continue to act as managing director.—Mr. J. W. P. Laird has been appointed assistant to the managing director of Messrs. Cammell Laird's Shipbuilding and Engineering Works, Birkenhead.

EGYPTIAN CONTRACT FOR BRITISH MANUFACTURERS.—We read in *The Board of Trade Journal* that tenders were recently invited by the Public Works Ministry, Cairo, for the supply and installation of pumping machinery at Atf, in Lower Egypt. This contract was open to manufacturers all over the world, and has now been adjudicated to the Associated British Manufacturers (Egypt), Limited, at a sum slightly over 70,000*l*.E. The contract was keenly competed for by Swiss, German, French, Dutch and other manufacturers. The installation forms part of one of the largest pumping stations in Egypt, and the machinery and material to be supplied is all British. It consists of four Willans and Robinson (The English Electric Company, Limited) Diesel engines, each direct-coupled to a Gwynne pump. Each unit is capable of pumping 6·4 cub. m. of water per second. The electric power required is supplied by two Vickers-Petter semi-Diesel engines direct-coupled to The English Electric Company's generators. The filtering plant is that of the Paterson Engineering Company, and the large sluice valves are supplied by Messrs. Glenfield and Kennedy.

SEASON-CRACKING IN CONDENSER TUBES.*

Further Studies in Season-Cracking and its Prevention. Condenser Tubes.

By H. MOORE, O.B.E., Ph.D., B.Sc., F.I.C., F.Inst.P., Member, and S. BECKINSALE, B.Sc., A.I.C., Member. (Communication from the Research Department, Woolwich.)

IN the discussion on a paper† presented to this Institute by the present authors two years ago, the president, Engineer Vice-Admiral Sir George Goodwin, suggested the application to Admiralty condenser tubes of the low-temperature annealing recommended for the removal of internal stress in brass. The present paper is a record of the work done in consequence of that suggestion.

This work consisted of :—

1. The examination of two split condenser tubes.

FIG. 1. SPLIT CONDENSER TUBES AS RECEIVED.

2. The determination of the properties of condenser tubes made by different makers.

3. Experiments on condenser tubes purposely made by methods leaving high internal stress.

4. An investigation of the rate of reduction of stress in condenser tube brass during low-temperature annealing.

5. The determination of the effect of heat-treatment, in the range 200 deg. to 325 deg. C., on the properties of brass of condenser tube composition.

The material used was either actual Admiralty condenser tubes (external diameter, $\frac{3}{4}$ in.; thickness of wall, 0·048 in.), or brass of Admiralty condenser tube composition (70 : 29 : 1).

1. *Split Tubes.*—The tube K had cracked in store. The length examined had an irregular longitudinal crack 0·05 in. wide at its widest part, and extending from one end to within 2 in. of the other end of the tube. The fracture and the external surface of the tube along one side of the crack were coated with black corrosion product. The tube L had cracked in service. Before it came into the authors' hands it had been cut longitudinally by a diametral cut about 90 deg. from the crack. The springing apart of the two halves shown in Fig. 1 indicated that longitudinal stress as well as circumferential stress had been present. The fracture surface of the crack was covered with corrosion product, but showed to some extent the crystalline appearance characteristic of season-cracks. A brownish-green corrosion scale covered the interior of the tube.

A piece of corroded tube cut from each sample was immersed in 5 c.c. of distilled water for one day. Precautions were taken to avoid contamination with ammonia from any other source. 1 c.c. of Nessler's solution was then added to each vessel. The water extract from K became brown, indicating the presence of ammonia, while that from L and a sample of distilled water submitted to the same conditions and test as a control remained clear and colourless. The tests were repeated a number of times and always with the same results.

The average Brinell hardness number of sample K was 147, that of L 160. The tests were made on the external surface, and each tube was uniform in hardness.

Microscopic examination revealed normal structures of much-twinned α crystals of medium size. The cracks in K, though corroded, were seen to be generally intercrystalline (Fig. 4). The smaller cracks were less corroded. Much corrosion had occurred in the cracks in L, but in some fields examined the path of the crack was seen to be intercrystalline.

2. *Properties of Admiralty Condenser Tubes.*—The material examined consisted of lengths of tube of $\frac{3}{4}$ in. external diameter selected at random from current supplies received from eight different makers. The different makes are distinguished in Table I, page 338, by the letters A to H. A second set of samples was obtained after an interval of some months. The remainder of the examination was carried out on the second set of samples only, except in the case of G and H makes of which samples in the first set only were received.

Short lengths of each tube were immersed for 5 minutes in 1 per cent. mercurous nitrate solution after pickling in nitric acid.* All were free from cracks on removal from the solution. The pieces cut from A make developed fine longitudinal cracks within 24 hours. None of the other pieces cracked during 56 days' storage in a closed space after the mercurous nitrate treatment. Short lengths were exposed over 0·880 ammonia solution in a closed space. Cracks developed in A and D makes. Pieces of tube A were annealed at 275 deg. C. for 1 hour and submitted to the mercurous nitrate test. No cracks developed. The microstructures (a solid solution) differed only in crystal size. The crystals were elongated in the direction of drawing.

Each tube was uniform in structure throughout its length. The finest and coarsest structures observed are shown in Figs. 2 and 3.

Brinell hardness tests made on the external and internal surfaces of the tubes with a ball of 2 mm.

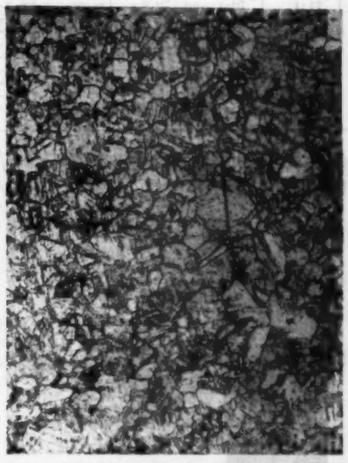


FIG. 2. × 100. GENERAL STRUCTURE IN TUBE D.

FIG. 3. × 100. GENERAL STRUCTURE IN TUBE G.

STRUCTURES OF TWO CONDENSER TUBES TAKEN FROM CURRENT SUPPLY, SHOWING MINIMUM AND MAXIMUM GRAIN SIZE.

FIG. 4. × 250. CORRODED SEASON-CRACK IN TUBE K.

diameter and a load of 40 kg., and on transverse sections with a ball of 1 mm. diameter and a load of 10 kg., showed a distinct rise in hardness from the exterior to the interior surface. The hardness of each tube was uniform throughout its length.

Low-Temperature Annealing.—Short lengths of each make were annealed in a salt bath at temperatures ranging from 250 deg. to 325 deg. C. In each treatment the temperature was maintained within ± 1 deg. C. Brinell hardness tests (2-mm. ball, 40-kg. load) were made on the external surfaces of the pieces before and after treatment, and the paper gives Brinell hardness numbers each of which is the average of at least six tests.

3. *Condenser Tubes in a State of High Internal Stress.*—Messrs. Muntz's Metal Company, Limited, were asked to supply a quantity of condenser tube in which high internal stresses were purposely induced by the method indicated by Vaudrey and Ballard. The tubes were otherwise to comply with the Admiralty specification. It was agreed that the tubes should satisfy the requirement that they should develop open cracks within 20 minutes of application of the mercurous nitrate test. The authors wish to acknowledge their obligation to Messrs. Muntz's Metal Company for the care taken in meeting these unusual requirements by preparing a considerable quantity of tube in which the internal stresses have been shown by subsequent experience to be not only very high but remarkably uniform. Thorough visual examination of the tubes, and pickling and microscopic examination of samples cut from each length, showed them to be free from cracks.

A number of pieces were submitted to the mercurous nitrate test, and each cracked within 40 seconds of immersion. The cracks gradually developed until they assumed the form shown in Fig. 5; microscopic examination showed that they followed the boundaries of the crystals, which were much twinned and medium in size.

Low-Temperature Annealing.—3-in. lengths cut from the tubes were heated in the salt bath at various temperatures and for varying periods of time. Four pieces were subjected to each treatment, the Brinell hardness was then determined on two and the mercurous nitrate test was applied to the other two. In the untreated state, this lot of tubing was found to be unusually susceptible to the development of cracks of the character of season-cracks and fire-cracks. This is regarded as an indication of the presence of exceptionally high stress, which might also be inferred from the form assumed after cracking (Fig. 5) and from the gaping of longitudinal cuts made in short lengths. Calculations of the actual value of the stress

* Abstract of a paper read before the Institute of Metals, on Wednesday, March 8.

† H. Moore and S. Beckinsale, "The Removal of Internal Stress in 70 : 30 Brass by Low-Temperature Annealing," *Journal of the Institute of Metals*, No. 1, 1920, vol. xxiii, page 225. ENGINEERING, vol. cix, page 393.

* This is the test indicated whenever the mercurous nitrate test is mentioned in the present paper. Full particulars of the method of applying the test have been given in the Appendix to a previous paper—H. Moore, S. Beckinsale, and C. E. Mallinson, "The Season-Cracking of Brass and other Copper Alloys," *Journal of the Institute of Metals*, No. 1, 1921, vol. xxv., page 35. ENGINEERING, vol. cxi, page 300.

TABLE I.—CHEMICAL ANALYSIS.

Make :	A.	B.	C.	D.	E.	F.	G.	H.
First Set of Samples.								
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Copper	70·6	69·9	70·2	70·4	70·5	—	70·7	70·5
Tin	0·82	1·01	0·92	0·92	0·50	—	1·01	1·08
Bismuth	0·003	0·0007	0·002	0·001	0·003	—	0·0029	0·003
Antimony	0·006	0·001	0·005	0·003	0·009	—	0·004	0·022
Arsenic	>0·01	>0·01	nil	>0·01	0·01	—	nil	0·02
Lead	0·30	trace	trace	trace	0·30	—	trace	0·14
Iron	0·03	0·04	0·04	0·05	0·11	—	0·11	0·04
Manganese	0·003	0·001	0·005	0·004	0·005	—	0·007	0·002
Brinell hardness number of external surface	149	147	135	156	118	—	137	133
Second Set of Samples.								
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Copper	68·9	70·1	71·2	71·1	70·1	70·8	—	—
Tin	1·04	0·89	0·88	0·99	0·83	1·13	—	—
Bismuth	—	—	—	—	—	0·005	—	—
Antimony	—	—	—	—	—	0·003	—	—
Arsenic	—	—	—	—	—	0·035	—	—
Lead	—	—	—	—	—	0·47	—	—
Iron	—	—	—	—	—	0·059	—	—
Manganese	—	—	—	—	—	0·0009	—	—
Nickel	—	—	—	—	—	0·025	—	—

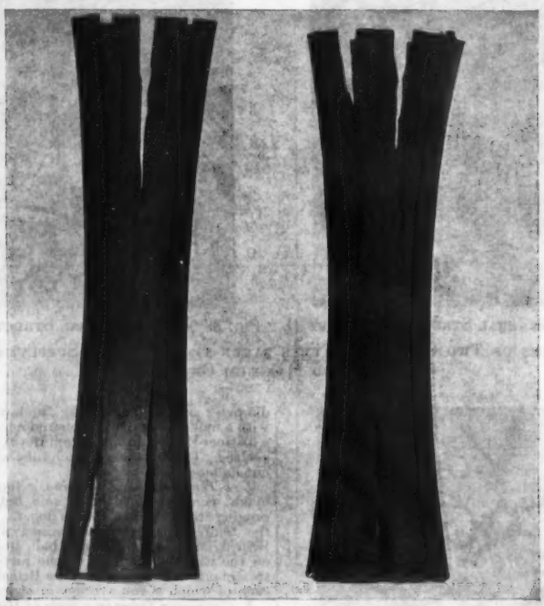


FIG. 5. CONDENSER TUBES IN A STATE OF HIGH INTERNAL STRESS, SHOWN AFTER TREATMENT IN MERCUROUS NITRATE SOLUTION.

are not given because of the uncertainty as to its mode of distribution. Considerable care had to be exercised in applying pickling and similar treatments, since the slightest trace of a mercury salt—introduced, for instance, by using vessels or tongs, which although they had been well rinsed in water had previously been used with dilute mercurous nitrate solution—caused cracks to develop in a very short time. The tube was highly susceptible also to the action of ammonia present in small concentration. Cracks have not developed, however, in conditions in which the presence of traces of mercury or ammonia could not be established, and when precautions to avoid the introduction of these "accelerating agents" were taken, pickling in acids or similar corroding treatment, however severe, did not cause the formation of cracks.

It has been widely believed that season-cracking may be brought about in brass by the action of stress alone, if the stress is sufficiently high and prolonged. This view is not supported by the experience of the authors, who have suggested elsewhere that for the development of season-cracks in brass at atmospheric or lower temperatures some chemical or similar action on the surface is necessary in addition to the presence of stress. The behaviour of this lot of highly-stressed condenser tube during the months in which it has been under observation and used in experiments has so far supported the views of the authors; but with the object of obtaining further evidence on the question they have placed a number of pieces of the tube in closed spaces in defined conditions of atmosphere in the spaces. The magnitude and uniformity of the stresses existing throughout a considerable quantity of material, its remarkable susceptibility to season-cracking, and its convenient form, make the tubing in question particularly suitable for the prolonged experiments contemplated. Lengths of 3 in. to 12 in. have been sealed up in glass tubes in a vacuum, and also in the air which happened to be present in the tube with and without the addition of a little water. Other specimens are being exposed to a considerable variety of conditions of surrounding atmosphere, and temperature variations will also be introduced. The sealed specimens can be examined through the wall of the glass containing tube without breaking the seal, and all specimens will be examined for cracks at intervals. The trial is intended to continue for many years, or until cracks have developed in all the specimens.

4. *The Removal of Stress.*—In the highly-stressed tubes used, treatment at 275 deg. C. for 2 hours, or at 300 deg. C. for 1 hour, reduces the stress below the limit at which cracks can be produced by the action of mercury and has very little effect on the hardness of the tubes. A series of similar treatments of spun cups made from sheet of Admiralty condenser tube composition, carried out in the manner previously described by the authors, showed that liability to crack under the action of mercury was removed in that case by a treatment at 275 deg. C. for 1 hour. In neither of these series of experiments was the actual initial stress determinable, and in each series the treatments were applied to specimens all of the same hardness. The work now to be described was intended to give quantitative information on the reduction of initial stress brought about by low-temperature annealing under different conditions of (1) initial hardness, (2) initial stress, (3) time, and (4) temperature of annealing. The effect of each of these four factors was determined independently.

The method adopted and the principles on which it is based have been described by the authors elsewhere.* If a flat strip of metal of uniform thickness is bent elastically to the form of an arc of a circle the uniform tension (p) at the outer surface can be calculated from the formula—

$$p = \frac{E\,t}{2\,r}$$

where t = the thickness of the strip,
r = the radius of the arc, and
E = Young's modulus of the metal.

If while the specimen is held in this form a treatment which will reduce the stress is applied and the strip is released after treatment, it will assume a form intermediate between its original straightness and the arc to which it was constrained during treatment. From the curvature assumed the stress present in the metal after treatment and before release can be calculated.

The material used was brass of Admiralty condenser tube composition containing 69·6 per cent. copper and 1·1 per cent. tin, and was cold-rolled to the desired thicknesses. The intermediate annealings and reductions in rolling were adjusted to give final Brinell hardness numbers, in the strip cold-rolled from the fully annealed condition, approximating to 120 and 160. These figures may be regarded as the lower and upper limits of the Brinell hardness of Admiralty condenser tubes.

Determinations of Young's modulus were made on a number of tensile test-pieces cut from cold-rolled Admiralty condenser tube brass with Brinell hardness ranging from 100 to 165, and gave the value 6,900 tons per square inch, with little variation.

The strips were 6 in. in length, and were elastically bent and held on formers to an arc of radius 3·5 in., as shown in Fig. 6. By using strips (of each hardness) of thickness 0·020 in. 0·015 in. and 0·010 in., initial tensions of approximately 20 tons, 15 tons and 10 tons per square inch were applied. The actual tension was calculated from the measured thickness of each strip. The treatments were carried out in a salt bath, as described above, with the exception of the more protracted treatments for which molten salt-jacketed air ovens were used.

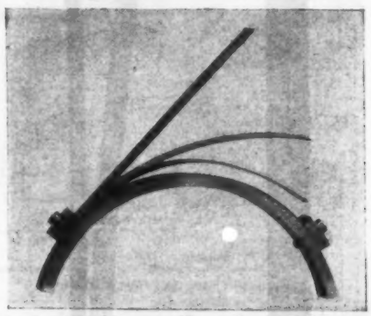


FIG. 6. FORMER AND FOUR STRIPS (STRAIGHT STRIP BEFORE BENDING AND TREATMENT; STRIP ATTACHED TO FORMER AT EACH END; TWO STRIPS RELEASED AT ONE END AFTER TREATMENT ON FORMER AND SHOWING PERMANENT DEFORMATION).

A number of strips of each hardness and thickness used were maintained for some time in the bent condition on the former at atmospheric temperature, and were then released to indicate whether the initial bending was purely elastic. In no case could any perceptible departure from straightness be detected in the strip after release. It should be noted, however, that the highest nominal tensile stresses applied exceed the limit of proportionality and in the case of the softer material approach the yield-point. It is possible, therefore, that the actual initial tensile stresses were in some cases slightly lower than the calculated 15 tons and 20 tons per square inch, but the very gradual departure from proportionality of strain to stress in tensile tests and the absence of perceptible permanent bending indicate that any error on this account is small. Typical series of results are shown graphically in Figs. 7 to 10 on the opposite page.

5. *The Effect of Heat-Treatment on the Properties of Condenser-Tube Brass.*—In a consideration of the application of such treatments to condenser tubes it is desirable that the effects on mechanical properties, more especially on the elastic range, should be known. This aspect of the question is the more interesting, in view of the effect of low-temperature annealing in raising the limit of proportionality (frequently termed the elastic limit) in cold-worked or otherwise overstrained material.

Part of the ingot from which the thin strips used in section 4 were prepared was cold-rolled from the fully annealed state into plate 0·75 in. thick. By suitable choice of the thickness at which the material was fully annealed before the final cold-rolling, plates of Brinell hardness approximately 98, 136, and 165 were obtained. Tensile test-pieces were cut from the plates with their axes parallel to the direction of rolling. The test-pieces were circular in section, the diameter was 0·564 in. and the gauge length 2 in. Extensions during loading were measured with a Ewing extensometer specially constructed for a 2-in. gauge length and reading to 0·000008 in.

The test-pieces, machined to finished dimensions, were submitted to treatments for various lengths of time in the range 200 deg. to 325 deg. C. in the salt bath, and after cooling were washed, re-measured and tested.

Results of these tests are given in load-extension diagrams in Fig. 11. A considerable number of the tests which gave results practically identical with those given by the untreated material have been omitted.

6. *General Conclusions.*—The cracks in the split condenser tubes examined showed the characteristics of season cracks. While these specimens were only two in number many examples have been examined elsewhere, and there is no reason to doubt that the splitting of

* H. Moore and S. Beckinsale, "The Prevention of Season-Cracking in Brass by the Removal of Internal Stress," Transactions of the Faraday Society, vol. xvii (1921), page 162. ENGINEERING, vol. cxi, page 665.

condenser tubes is an example of the season-cracking of brass. The cracks commonly follow an intercrystalline path, and the springing apart occurring on the formation of a crack indicates the relief of initial stress. The tube which had cracked in store resembled other specimens of season-cracked brass investigated by the authors in having ammonium compounds present in the corrosion product coating the fracture. The freedom of the corrosion product of the other tube from ammonium compounds may be due to their removal by water while the tube was in service.

The possibility of sewage contamination in sea water circulating through condenser tubes has been pointed out by G. B. Allen.* The presence in the cooling water of ammonium compounds arising from this source is dangerous when the tubes are in a state of internal stress, owing to the powerful effect of ammonia and its compounds in inducing the cracking of stressed brass. This emphasises the wisdom of ensuring that condenser tubes are not taken into service in a state of high stress.

The examination of many different makes of tubes showed that the Brinell hardness was usually between 140 and 160. One unusually soft tube (Brinell hardness 118) contained only 0·3 per cent. of tin, and appears to be quite exceptional in its composition and properties. Generally the tubes were free from injurious stress, but the cracking of two tubes out of the limited number examined, under the action of ammonia (one of these cracked after mercury treatment also), suggests that freedom from injurious stress cannot be assumed in tubes which are supplied and accepted for Admiralty use. More important evidence of the presence of injurious stress in condenser tubes is their occasional failure by splitting, and the clear indication of initial stress relieved by the splitting, in the gaping of the cracks and the springing apart when cuts are made.

The experimental work reported in the present paper has been mainly directed to the subject of the reduction of internal stress by low-temperature annealing, and the effect of such treatments on the strength and range of elasticity of condenser tubes. The work carried out comprised the heat-treatment of spun cups (not described in detail) of highly-stressed condenser tubes, of strips of condenser tube brass maintained in a form causing a known initial stress, and of tensile test-pieces of the same material. The behaviour of Admiralty condenser tube brass (70 : 29 : 1) throughout was found to be similar to that of 70 : 30 brass, as might be expected.

The experiments on the low-temperature annealing of internally-stressed condenser tubes and spun cups agreed with the quantitative results yielded by the work on elastically bent strips of Admiralty condenser tube brass, in which strips cold-rolled to 120 and 160 Brinell hardness initially stressed to 10 tons, 15 tons and 20 tons per square inch maximum tension at the surface, were annealed at temperatures in the range 200 deg. to 325 deg. C. The results may be summarised in the following conclusions, which are equally applicable to 70 : 30 brass.

1. The rate of reduction of stress at the lower temperatures is fairly rapid at first, but becomes slow when the stress has been considerably reduced. Important stresses remain after 6 hours at 200 deg. or 225 deg. C.

2. As the temperature is raised the rate of reduction of stress increases, but shows the same characteristic of slowing down as the stress falls during the treatment.

3. The higher the initial stress, the higher is the remaining stress after a given treatment in condenser tube brass of the same hardness, although the amount of stress removed is greater the higher the initial stress.

4. The higher the hardness of the brass, the lower is the remaining stress after a given treatment and for a given initial stress.

5. A large reduction in the amount of stress is brought about by annealing conditions (temperature and time) which raise slightly the hardness of the cold-worked material, and the stress can be reduced to a low value, at which it appears to be innocuous, by treatments which do not appreciably lower the hardness and strength.

Tensile tests made on condenser tube material cold-rolled to a Brinell hardness of 165 and heat-treated in the range 200 deg. to 300 deg. C. showed that the proportional limit is considerably raised by such treatment. The yield-point is raised to a smaller extent, while the maximum stress is little affected at the lower temperatures and is gradually lowered as the temperature is raised. At temperatures above 300 deg. C., and at 300 deg. C., if the treatment is prolonged, the limit of proportionality and yield-point begin to fall off again. The improvement in elastic properties after suitable treatment is an example of the recovery of elasticity brought about when overstrained materials are heated to temperatures below the range at which true "annealing" or softening begins. The best results are given, in the case of hard condenser tube brass, by treatment for moderate times in the range 225 deg. to 275 deg. C., the limit of proportionality being raised, in the tests reported, from 12 to 20, and the yield-point from 32 tons to 35 tons per square inch. The elongation is also improved. The condenser tube brass in which the initial hardness had been raised to a less extent by cold-rolling gave little indication of improvement in elastic properties by "recovery" heat-treatment, the effect of which is in general greater the more the material has been overstrained, but on the other hand higher temperatures and longer treatments may be applied to the softer brass without appreciable lowering of the limit of proportionality, yield-point, of maximum stress.

In the application of low-temperature annealing for the purpose of preventing season-cracking, the practical questions to be decided are (1) to what limits should the initial stress be reduced, and (2) what treatment is required to bring about the desired reduction under ordinary manufacturing conditions. It is not yet possible to fix a limit of stress below which season-cracking cannot occur, but there is much evidence indicating (1) that the initial stress in brass objects which fail by season-cracking is fairly high (say, over 10 tons per square inch) as a rule, if not always; (2) that failure by season-cracking is improbable, if not impossible, when the stress is not more than 4 tons or 5 tons per square inch; and (3) that brass which does not crack under mercury treatment is unlikely to develop season-cracks. Exceptionally severe conditions, such as exposure to an atmosphere consisting mainly of ammonia gas, may however, induce cracking when the stress is lower. It is hardly necessary to provide against a condition such as this, in which brass is rapidly destroyed by corrosion. The experimental results indicate that treatment in the range 260 deg. to 300 deg. C. should reduce the stress below 5 tons per square inch, the higher temperatures being required for higher initial stress and lower initial hardness.

In order to reduce the stress below the limit at which mercury treatment causes cracking in the experimental tubes in which high initial stress had been purposely developed, treatment at 275 deg. C. for 2 hours, or at 300 deg. C. for 1 hour, was found necessary. There is no doubt that in these tubes the initial tension at the surface was extremely high. It is most improbable that such highly-stressed tubes would ever be supplied for use, and although treatment at 275 deg. C. for 2 hours may be applied without appreciable loss of strength, a shorter treatment at this temperature would be sufficient to reduce stress to a safe limit in condenser tubes as manufactured.

It is considered that treatment at 260 deg. to 300 deg. C. for 30 minutes would remove all liability to the development of season-cracks in Admiralty condenser tubes, and would at the same time effect a useful improvement of mechanical properties, especially in the harder tubes, by raising the limit of elasticity. Treatment for longer at a lower temperature could be applied with equally good results.

G. D. Bengough and O. F. Hudson* have described a treatment for the production of an oxidised scale on condenser tubes for the prevention of corrosion. The finished tube is heated in an oxidising atmosphere for half an hour at 280 deg. C. ± 20 deg. It will be seen that this treatment is very similar to that now recommended for the prevention of season-cracking, and that the one treatment would answer both purposes. If the pre-oxidising process is to be adopted as a preventive of corrosion, there would be no difficulty in adjusting the time and temperature, so that the conditions were the

REDUCTION OF STRESS IN BENT STRIPS OF COLD-ROLLED BRASS OF ADMIRALTY CONDENSER TUBE COMPOSITION BY TREATMENT AT 275° CENT.

Fig. 7.

Initial Brinell Hardness, 121.
Initial Stresses, R 20·0, S 15·6, & T 10·9 Tons per Sq. In.

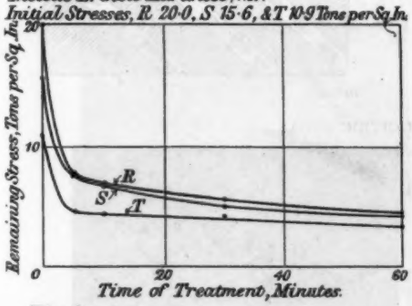
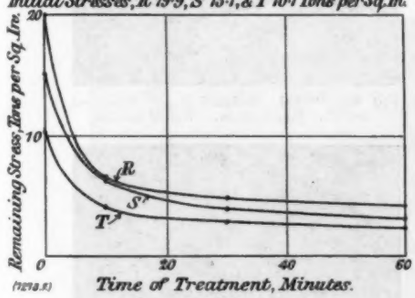


Fig. 8.

Initial Brinell Hardness, 167.
Initial Stresses, R 19·9, S 15·1, & T 10·1 Tons per Sq. In.



REDUCTION OF STRESS IN BENT STRIPS OF COLD-ROLLED BRASS OF ADMIRALTY CONDENSER TUBE COMPOSITION BY TREATMENT AT 300° CENT.

Fig. 9.

Initial Brinell Hardness, 123.
Initial Stresses, R 20·0, S 15·6, & T 10·8 Tons per Sq. In.

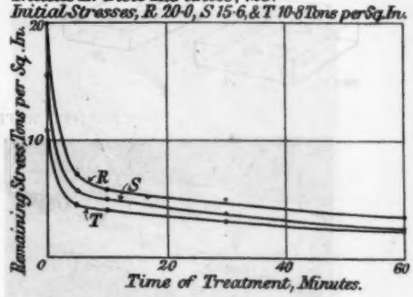


Fig. 10.

Initial Brinell Hardness, 168.
Initial Stresses, R 19·9, S 15·1, & T 10·0 Tons per Sq. In.

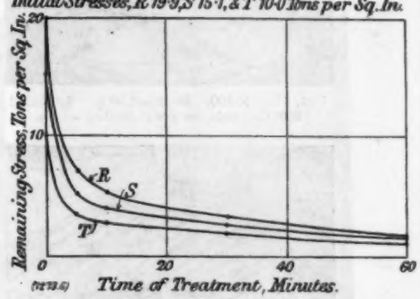
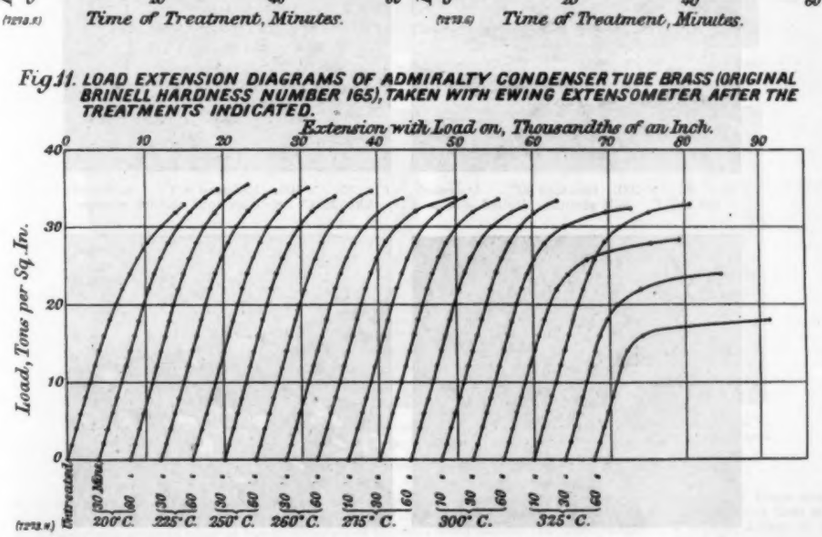


Fig. 11. LOAD EXTENSION DIAGRAMS OF ADMIRALTY CONDENSER TUBE BRASS (ORIGINAL BRINELL HARDNESS NUMBER 165), TAKEN WITH EWING EXTENSOMETER AFTER THE TREATMENTS INDICATED.



* G. B. Allen, "Service Experience with Condensers," *Journal of the Institute of Metals*, No. 2, 1920, vol. xxiii, page 285, ENGINEERING, vol. cx, p. 423.

* G. D. Bengough and O. F. Hudson, "Fourth Report to the Corrosion Committee," *Journal of the Institute of Metals*, No. 1, 1919, vol. xxi, page 207, ENGINEERING, vol. cvii, page 417.

most suitable for the reduction of stress to a safe limit. If, however, an oxidised surface is not desired, the conditions under which the stress reduction treatment is applied can be controlled to prevent oxidation entirely.

The authors are indebted to Engineer Vice-Admiral Sir George Goodwin, K.C.B., LL.D., Engineer-in-Chief of the Fleet, for the supply of material and much essential information, and for his helpful advice during the progress of the investigation.

THE INTERNAL MECHANISM OF COLD-WORK AND RECRYSTALLISATION IN CUPRO-NICKEL.*

By FRANK ADCOCK, M.B.E., B.Sc., Member (Teddington).

(*Concluded from page* 308.)

Change of Hardness with Annealing Temperature.—The curve included in Fig. 5 shows the change in hardness of the 88 per cent. reduced material when the specimens were annealed at gradually increasing temperatures, and it has been constructed from the results shown in Table I, on page 305 *ante*. An inspection of the curve shows that appreciable softening of the metal only set in when the annealing temperature was above that at which recrystallisation had commenced. Thus a specimen annealed at 440 deg. C. showed the new crystal grains under the higher powers, but the hardness only began to fall rapidly when the annealing temperature reached 460 deg. C. Although the fall in hardness became less marked at a temperature corresponding roughly with the complete disappearance of all non-recrystallised material, yet a steady softening of the metal seemed to take place even up to annealing temperatures as high as 970 deg. C.

Examination of the 50 per Cent. Reduced Series.—As in the case of the 88 per cent. reduced samples, the 50 per cent. reduced material was annealed for periods of half an hour at temperatures shown below in Table II.

TABLE II.

Sample.	Annealing in Degrees C. Range.	Temperature Centigrade. Average.
M6	435–440	437
M3	480	480
M5	495–505	500
M7	520–525	522
M2	535–545	540
M8	560	560
M9	665	665
M4	Unannealed	—

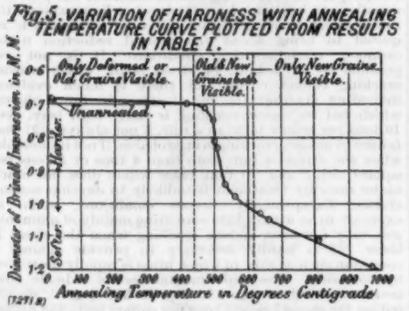


Fig. 5. VARIATION OF HARDNESS WITH ANNEALING TEMPERATURE. CURVE PLOTTED FROM RESULTS IN TABLE I.

Owing to the large grain size of the original material, it was impossible to obtain satisfactory indications of the hardness of the specimens by the Brinell method, as the impressions made by the ball were very irregular.

Reference has already been made to the characteristics of the unannealed metal, and the various samples which have been annealed will be dealt with in turn.

M6 *Annealed* 435 *Deg. to* 440 *Deg. C.*—A general view of the "side" section of the specimen has already been shown in Fig. 15, page 306 *ante*, and Fig. 33, page 307 *ante*, illustrates at higher magnification a rather peculiar formation near the boundary of one of the original crystal grains. The dotted lines observable in the last mentioned figure were resolved under the oil-immersion objective into chains of etch-pits approximately cubic in shape, but no new crystal grains could be detected.

M3 *Annealed* 480 *Deg. C.*—Changes had evidently been taking place in the material, for the dark sloping lines occasionally visible in the "side" sections of the unannealed material had given place to chains of minute etch-pits which almost covered the surfaces of some of the old grains. (See Figs. 34 and 35.) The process of recrystallisation was yet in the early stages, and only a few isolated new grains could be distinguished under the microscope.

M5 *Annealed* 495 *Deg. to* 505 *Deg. C.*—As with the 88 per cent. reduced specimens at this stage, the process of recrystallisation in some of the old grains was more advanced than in others. Thus a large number of new grains had appeared on the etch-bands in one of the old grains depicted in Fig. 36, but only a few new grains were to be seen within the borders of most of the neighbouring old grains which did not show well-marked strain lines on etching.

M7 *Annealed* 520 *Deg. to* 525 *Deg. C.*—The average size of the new grains had considerably increased, and it was apparent from the surface etching that their orientations were in many cases very different from that of the old grains in which they were growing. While Fig. 37 illustrates the tendency of the new grains to form in lines or bands, the next photograph (Fig. 38) shows another field of the same sample where some of the new grains had formed at the boundaries of the old grains. Attention is drawn to the slightly stepped appearance of the old grain boundary where several of the new grains had developed. In some instances the bands of new grains did not terminate exactly at the boundary of the old grain, and Fig. 39 illustrates the manner in which the new grains have penetrated the original boundary of the deformed crystal grain.

M2 *Annealed* 535 *Deg. to* 545 *Deg. C.*—The new grains had somewhat increased in size, but unlike the corresponding samples in the 88 per cent. reduced series, it was only occasionally when examining the "top" sections that the new grains were found in well-defined bands running in a direction at right angles to the direction of rolling.

M8 *Annealed* 560 *Deg. C.*—As with several of the previous specimens, the surfaces of the old grains were found to be intersected with chains of new crystal grains which had developed on the sites of the strain lines observed in the unannealed samples. The specimen was deeply etched in order to ascertain whether any relationship existed between the orientation of the old grains and of the new, but although the etch-pits revealing the direction of the crystal grain structure remained approximately constant over large areas of the old grains examined, it was only in exceptional instances that the orientation of the new grains was demonstrated by the same method. In spite of the absence of visible etch-pits, the orientation of one grain could be distinguished from that of another by the tendency of the surface to etch up, in rather vague lines, which as far as could be determined remained parallel within the boundaries of a single grain, and it was concluded after the examination of a large number of fields that no direct relationship existed between the orientation of the new grains and that of the old. Fig. 40 shows a typical field of view, and although the magnification is not sufficient to show the details of the surface etching, it will be noticed that most of the new grains are either lighter or darker in appearance than

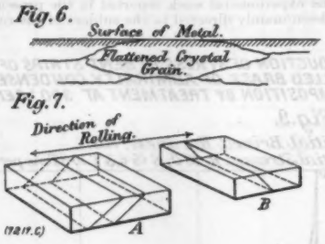


Fig. 6.

Fig. 7.

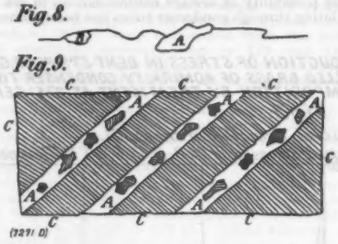


Fig. 8.

Fig. 9.

ETCHED WITH CITRIC ACID.

FIG. 34. × 100. Reduced 50%. Annealed 480° C. Side section. Rolled ←→

FIG. 35. × 350. Reduced 50%. Annealed 480° C. Side section. Rolled ←→

FIG. 36. × 100. Reduced 50%. Annealed 495-505° C. Side section. Rolled ←→

FIG. 37. × 100. Reduced 50%. Annealed 520-525° C. Side section. Rolled ←→

FIG. 38 × 350. Reduced 50%. Annealed 520-525° C.

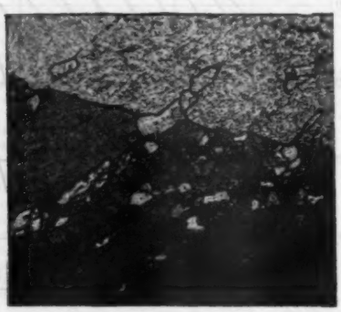


FIG. 39. × 350. Reduced 50%. Annealed 520-525° C.

[Slightly reduced in reproduction.]

* Paper read before the Institute of Metals, on Wednesday, March 8.

the old ones. Several interesting cases of incomplete boundaries were seen at this stage—one of which is shown in Fig. 41. Caution must be exercised in the interpretation of the photomicrograph, for a certain amount of smearing of the surface may have taken place during polishing, especially where the crystal grain boundaries approach the surface of the metal at a very acute angle. (See Fig. 6.)

M9 *Annealed 665 Deg. C.*—The process of recrystallisation was now completed, and the metal exhibited the usual structure of a metal which had been cold-worked and afterwards annealed.

General Observations and Summary.—(1) The original crystal grains became roughly "fish" shaped during the process of rolling.

(2) Some of the crystal grain boundaries undoubtedly made acute angles with the surface of the "top" section of the specimens, and this, together with a certain amount of smearing effect during polishing, perhaps explains the apparent duplication of some of the boundaries of the deformed grains depicted in Figs. 12, page 306 *ante*, and 41.

Fig. 6 indicates how it is possible for the boundary of a flattened grain to make an acute angle with the "top" section.

3. The dark lines or bands which appeared on etching the "side," "top," and "end" sections of the unannealed material (see Figs. 10 and 12, page 306 *ante*), are really the traces of planes which passed through the alloy in directions shown in Fig. 7.

4. Two sets of planes as illustrated in (A) and (B) of Fig. 7, were discovered in the worked metal, but the two sets were not found co-existent within the boundaries of any single deformed crystal grain.

5. During the operation of rolling the crystal grains were caused to "slip" or "fault" along the planes referred to above. This conclusion is supported by the stepped appearance of the crystal-grain boundaries shown in Figs. 14 and 15, page 306 *ante*.

6. The "slip" or "fault" planes were, as expected, more numerous in the 88 per cent. reduced than in the 50 per cent. reduced metal, but even in the former case old distorted crystal grains existed where the usual surface etchings were absent and only faint striations were visible, running in the direction of rolling.

7. A connection appeared to exist between the original orientation of the crystal grains in respect to the direction of rolling and the appearance or non-appearance of the "slip" or "fault" planes.

8. The orientation of a moderately deformed (50 per cent. reduction) grain in the cupro-nickel remained approximately constant throughout most of its volume, but regions existed where changes of orientation could be detected. (See Figs. 16 and 17, page 306 *ante*). The possibility of the actual "bending" of the crystalline structure during deformation is seemingly in opposition to existing views, for in their paper on "Crystal Growth and Recrystallisation in Metals," Carpenter and Elam state: "There is no evidence known to the authors that after deformation the orientation of a crystal differs in any way throughout its extent."

9. Samples annealed at temperatures just too low to bring about visible recrystallisation showed both the usual etch-bands, and the horizontal striations visible in the "side" sections, much more clearly than the unannealed specimens. Apart from their direction, the horizontal markings ("side" section) and the sloping etch-bands could be distinguished by the more definite, if sometimes more delicate, nature of the former. During the early stages of recrystallisation, and before many new grains were visible, the horizontal striations sometimes became very pronounced and after deep etching resembled ordinary crystal grain boundaries, except that they were often nearly straight and quite finite in length. On the other hand, the deep etching of areas of the partially annealed specimen where the "slip" planes came to the surface merely resulted in the formation of chains of rather irregular etch-pits.

10. The new grains which appeared in the specimens treated at the proper annealing temperature were always found associated with:—

(*a*) Etch bands which represented the traces on the surface of the specimen of the sloping "slip" planes;

(*b*) Striations running parallel to direction of rolling (see paragraph 9); or

(*c*) Boundaries of deformed crystal grains and mechanical inclusions.

Examination of the 88 per cent. reduced metal which had been annealed so as to show only a few new grains, always revealed these recent arrivals situated in the "slip" planes.

Viewed from the "side" section, the new grains were not equiaxed, and in most cases were much longer in the direction of the neighbouring etch-bands. (See Figs. 39 and 40.)

It was noteworthy that in this type of recrystallisation the new grains were not elongated in the direction of rolling. When the old grains showing the sloping etch-bands ("side" section view) has almost entirely recrystallised, the process commenced in the old grains marked by the horizontal striations. Owing to the more definite nature of the striations, as explained in paragraph 9 above, the process of recrystallisation appeared essentially different from that which was associated with the sloping etch bands, and the new grains now appeared elongated in the direction of the striations, which were themselves parallel to the direction of rolling. (See Fig. 28, page 307 *ante*.)

A resemblance will be observed between Fig. 23 of this paper and Fig. 16 of Carpenter and Elam's paper on "Stages in the Recrystallisation of Aluminium Sheet on Heating," which is reproduced in Fig. 8.

While, however, the new grains always appeared at the boundaries of the old grains in the aluminium sheet, this was not so with the cupro-nickel, where the new grains were to be found on the striations within the deformed crystal grains.

In some of the deformed grains both the sloping etch-bands and the striations influenced the arrival and growth of the new grains. Thus Fig. 27, page 307 *ante*, depicts a group of new grains which appeared on the site of a sloping etch-band, but some of the members of the group showed a decided tendency to elongate along the striations, which are also visible in the figure.

Again, in Fig. 23, page 307 *ante*, the new grains have evolved on the well-defined striations, but one of the grains has grown preferentially in the direction of a faintly marked etch-band which crosses the striation, where the new grain has appeared.

Figs. 36 and 37 and 40 reveal the fact that some of the old crystal boundaries in the deformed metal had little to do with the new grains which were produced on annealing. Where early recrystallisation took place at old crystal boundaries, it is suggested that the cause is to be found in the excessive straining at or near the boundary in question and not to some special property of the boundary. Reference is again made to Fig. 38, which illustrates the new grains forming at the old grain boundary and also within the body of the grain at the same time. That the old grain boundaries do not present obstacles to the growth of new grains is indicated in Fig. 39, where a band of new grains has evidently grown across an old grain boundary.

Some of the experimental facts connected with recrystallisation are explained by the following rather crude theory:—

(*a*) The etch bands are the traces of planes along which slip has taken place during rolling.

(*b*) These planes, or rather zones, contain a certain amount of amorphous material in which are embedded crystalline fragments of débris rubbed from the crystalline grains during the process of "slipping" or "faulting."

(*c*) On annealing these fragments grow chiefly into the amorphous material and give rise to bands of new crystals, which can be seen in the partially annealed specimens, Fig. 36.

(*d*) Since more amorphous material will be available in the direction of the strain planes, the new crystal grains will naturally grow more readily in these directions and thus produce the elongated grains visible in Fig. 40.

(*e*) The crystalline fragments which form the nuclei of the new grains will from their mode of formation be orientated (as regards their crystalline structure) quite at random in respect to one another and to the crystalline grain from which they were detached.

This explains the appearance of new crystal grains with widely different orientations—an experimental fact which certainly does not conform to the view that during cold-working the old crystal grains are separated by amorphous material into sections of slightly different orientations, and that these comparatively large sections give rise to the new grains on annealing and determine their crystalline orientations. Were this the case, the new grains produced on partially annealing a specimen of moderately cold-worked cupro-nickel could be considered in groups—each group corresponding with one of the distorted grains, and the orientation of the grains of each group would remain almost constant throughout. This is the outcome of the fact that the structure of the distorted grains previous to annealing is revealed by etch-pits, and except for a few regions is known to remain approximately constant within the borders of any single grain.

That the recrystallisation follows the strain or "slip" planes indicated in Fig. 7, can be seen from Figs. 19 and 20 ("side" section), Fig. 21 ("end" section), and Figs. 25 and 26 ("top" section), on page 307 *ante*.

Fig. 9 shows quite simply the condition of the cold-worked metal according to the above theory.

(*a*) Amorphous material in which the crystalline fragments are embedded.

(*c*) Comparatively large masses of crystalline material from which the fragments were detached.

11. Unusual features were detected in the last stages of recrystallisation—that is, when the last portions of the

ETCHED WITH CITRIC ACID.

FIG. 40. × 100. Reduced 50%. Annealed 560° C. Side section. Rolled ←→

FIG. 41. × 650. Reduced 50%. Annealed 560° C. Side section.

FIG. 42. × 100. Reduced 50%. Annealed 665° C. Side section.

FIG. 43. × 100. Reduced 88%. Annealed 520-540° C. Side section. Rolled ←→

FIG. 44. × 350. Reduced 88%. Annealed 520-540° C. Side section. Rolled ←→

FIG. 45. × 100. Reduced 50%. Annealed 545°C. Specimen scratched for identification purposes.

[Slightly reduced in reproduction.]

non-recrystallised metal were being invaded by the new grains. Deformed grains characterised by the striations in the direction of rolling were the last to recrystallise, and, provided that the annealing temperature was suitably regulated, gave rise to abnormally large new grains, as will be seen from Figs. 29 and 31, page 307 *ante* ("end" section). It is suggested that for some reason, probably connected with the original orientation of such a grain before rolling, few centres of recrystallisation are available, and these only become active at an unusually high annealing temperature.

At a certain stage in the annealing process some of the old crystal grains, characterised by their sluggishness in recrystallising, appeared much darker after etching than the new grains growing in and around them. Fig. 43 shows the general contrast in the surface aspect of the old and new crystal grains after etching, and Fig. 44, taken at higher magnification, demonstrates that the old or unrecrystallised material has been roughened to a greater extent by the action of the etching reagent than the new grains visible in the same field. It is of interest to note that Carpenter and Elam observed that in certain cases the new crystals which became apparent on annealing worked aluminium sheet were white in contrast with the non-recrystallised material, which was darkened or roughened by the etching reagent.

12. In order to ascertain whether the deformed crystal grains "grew" to an appreciable extent during the operation of annealing, specimens marked with fine scratches were employed, but as they had to be repolished after each heating accurate measurements were not attempted. It was concluded that when recrystallisation had proceeded to the stage shown in Fig. 45 the outline of the deformed grains had not shown signs of movement.

The author desires to acknowledge his indebtedness to Professor C. H. Desch, D.Sc., Ph.D., for his supervision of the above investigation, and also to Messrs. W. and H. Turner, of Sheffield, who undertook the rolling of the samples. The work was carried out in the laboratories of the Department of Metallurgy of Sheffield University with the assistance of a grant from the Department of Scientific and Industrial Research.

ELECTRIC STEEL CASTINGS IN CANADA AND THE UNITED STATES.—We read in *The Iron Age*, New York, that out of 22,409 tons of steel castings produced in Canada last year, 13,984 tons, or 62·4 per cent., were made in electric furnaces. And this was done in a year of depression when the country's total steel output fell to 56,000 tons per month, from 92,000 tons per month in 1920. The best record in the production of electric steel castings in the United States was in 1920, when the castings made in electric furnaces were only 12·4 per cent. of the total, and the United States leads the world in the use of the electric furnace. Electric power is cheap in Canada and the steel foundry is profiting thereby.

COAL IN CHINA.—The Ching Hsing Coal Company, operating in South Shangtung, plans to sink a new pit to augment its daily output in three years time to 3,000 tons in place of the present output of 1,500 tons. The Japanese Fushun Collieries in Manchuria have planned a ten-year programme of improvements and extensions. Their present daily output is 10,000 tons, but according to plans for the period ending 1929, the output is to be raised from 3,000,000 tons to 8,000,000 tons a year. The improvements include the laying down of a plant for the extraction of petroleum from the oil in the shales above the coal seams. Within three years the Sino-British Kailan Mining Administration hopes to increase its daily output from 15,000 tons to 20,000 tons. The improvements consist in the sinking of a new mine of 5,000 tons capacity, enlarging the existing coal-washing plant, erection of by-product ovens, and the construction of a new wharf at Tangku. The Pekin Syndicate has increased its daily coal output to nearly 4,000 tons from 2,300 tons by the opening of several new pits. The Pei Piao Coal Company, operating near Chao-yang, Chihli, has a capital of 5,000,000 dols., half of which has been subscribed by merchants and the other half by the Peking-Mukden Railway. The coal has been found to be an excellent steam coal, suitable for locomotive and marine boilers. Arrangements are being made for construction of a branch line from the Peking-Mukden Railway to the coalfield. The Men Tou Kou Coal-Mining Company owns a concession at Mentoukou, 16 miles from Peking. This is a Sino-Foreign organisation with a capital of 1,000,000 dols. Its output, anthracite, is the popular household coal of Peking. The Tung Pao Company, Tatung, Shansi, has a capital of 3,000,000 dols., raised by Shansi merchants in co-operation with Cantonese. The coalfield has two kinds of coal, smokeless at the top, and high-class steam for locomotives and steamers at the bottom of the coal-bearing series. The Liu Ho Kou Collieries in Honan have planned to increase their daily output from 600 tons to 1,500 tons within two years time. A standard gauge railway has been built to Fenglochen, replacing the narrow-gauge railway. The Chihli Lincheng Mines will increase their daily output to 1,500 tons through the sinking of a new shaft. Speaking on the annual dinner of the China Institution of Mining and Metallurgy, held at Peking on December 28, Mr. K. Y. Kwong (vice-president), in an address on "The Mining Industry in China," said that in his opinion the total annual coal production for China was between 20,000,000 tons and 25,000,000 tons. The annual production of the Hanyeh-ping Company's Collieries at Pinghsiang is about 1,000,000 tons; that of Chinghsing the Mining Administration about 360,000 tons; and that of Okura and Co.'s mines at Penchihu about 300,000 tons.

THE EFFECT OF IMPURITIES ON RECRYSTALLISATION AND GRAIN GROWTH.*

By the Research Staff of the General Electric Company, London. (Work conducted by Major C. J. SMITHELLS, M.Sc.)

THIS research was undertaken to determine the effects of small quantities of impurities in tungsten on the structure developed on annealing.

The paper is divided into three parts, dealing with:—

1. Experimental work showing the effect of impurities in modifying recrystallisation and crystal growth in worked tungsten.
2. The explanation of these facts by a new hypothesis.
3. A critical survey of existing literature on the subject of recrystallisation and crystal growth in worked metals in the light of these results.

PART I.—EXPERIMENTAL.

Preparation of the Metals.—A series of batches of tungsten containing accurately known amounts of different impurities have been used in this research.

The ore used was scheelite, a natural calcium tungstate containing chiefly iron and silica as impurities, together with traces of nearly all the elements. This was digested with hydrochloric acid, leaving a residue of silica and tungstic oxide, from which the liquid was decanted. After washing, the tungstic oxide was dissolved in ammonia, filtered, and reprecipitated with boiling hydrochloric acid. The oxide was washed and dried, and contained 99·95 per cent. WO_3. The impurity remaining was 0·05 per cent. calcium tungstate. This oxide was redissolved in ammonia and reprecipitated, and after washing and drying was considered "chemically pure." All the metals used were prepared from this oxide.

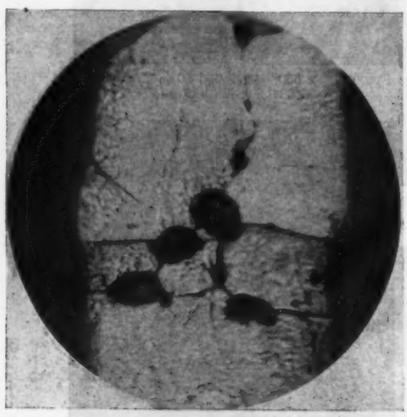


FIG. 1. TUNGSTEN CONTAINING 0·1 PER CENT. ALUMINA. ANNEALED FOR 600 HOURS IN PRESENCE OF PHOSPHORUS VAPOUR. × 1000.

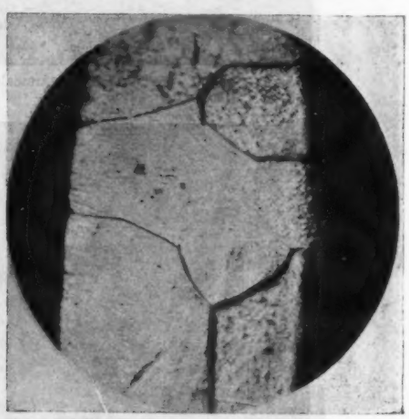


FIG. 2. TUNGSTEN CONTAINING 0·1 PER CENT. ALUMINA. ANNEALED FOR 600 HOURS IN ABSENCE OF PHOSPHORUS VAPOUR. × 1000.

Metal A (99·95 + *per Cent. Tungsten*).—The oxide was dissolved in ammonia, and the solution of ammonium tungstate evaporated and allowed to crystallise. The first crop of crystals only were taken, and ignited to give pure tungsten oxide.

The pure oxide was reduced in hydrogen in silica tubes, and the resulting metal powder pressed, sintered, swaged and drawn into wire in the usual manner for the preparation of ductile tungsten.

Metal B (0·01 per cent. Al_2O_3, 0·1 per cent. SiO_2).—The oxide was heated to about 900 deg. C. in a fireclay crucible before reduction. This results in the introduction of small quantities of alumina and silica into the oxide. The amount introduced varies with the conditions, and in this metal 0·1 per cent. of each oxide was found by analysis. After grinding and sieving the oxide was reduced, &c., as before. During the sintering process about one-half the silica introduced is volatilised; but for comparison it is convenient to refer to the amount introduced into the various oxides. The proportion of silica lost is found to be roughly constant in all cases.

Metal C (0·7 per cent. ThO_2).—The oxide was made into a creamy paste with water and a solution of thorium nitrate, containing the calculated quantity of ThO_2, was intimately mixed with it, stirring being continued during evaporation to dryness. After grinding and sieving a very uniform distribution of the thoria was obtained. Reduction, &c., followed as before.

Metal D (0·7 per cent. ThO_2, 0·2 per cent. CaO).—This was prepared in a similar manner, the calculated quantity of CaO being introduced as chloride with the thorium nitrate.

Metal E (0·1 per cent. Na_2O, 0·25 per cent. ThO_2); *Metal F* (0·1 per cent. Na_2O, 0·5 per cent. ThO_2); *Metal G* (0·1 per cent. Na_2O, 0·75 per cent. ThO_2); *Metal H* (0·2 per cent. Na_2O, 0·75 per cent. ThO_2).—The oxide was made into a paste as before, and the calculated quantity of a solution of sodium chloride stirred in. Thorium nitrate solution was then added, and evaporation to dryness carried out as before. An interesting observation, which has an important bearing on the discussion in a later part of this paper, was made after the reduction. In all the metals containing sodium small purple-red crystals could be picked out under the microscope. The silica tube in which the reduction was carried out became coated on the inside, after frequent use, with similar metallic-looking crystals.

When tungstic oxide and a sodium salt are reduced at a high temperature, sodium tungsten "bronzes" are formed. These vary in colour and in composition, and their constitution is unknown. The formula ascribed by Philipp to the purple red crystals is $Na_2W_3O_9$, and our analyses given below confirm this composition, although great accuracy has not been possible with the small amounts separated from the metal powder.

	Found.	Calculated.
Tungsten	75·10	74·4
Sodium	4·74	6·20

The bronze has a metallic lustre, crystallises in the cubic system, and is hard and brittle. It is not affected by acids or alkalis. Roscoe and Schorlemmer state that it is attacked by hydrofluoric acid, but we have not been able to detect any action even on boiling with a mixture of hydrofluoric and nitric acids. The subsequent fate of these bronze crystals is discussed later in the paper.

Metal J (0·1 per cent. Na_2O, 0·2 per cent. SiO_2); *Metal K* (0·1 per cent. Na_2O, 0·4 per cent. SiO_2).—The tungstic oxide was dissolved in caustic soda and a quantity of sodium silicate, calculated to introduce the required amount of SiO_2, was added. Precipitation of the tungstic and silicic acids was effected with hydrochloric acid, and the precipitate washed and dried. It was found that by this method about 0·2 per cent. of sodium chloride was absorbed by the tungstic acid, and could not be removed by subsequent washing.

Metal L (0·1 per cent. Na_2O).—As has been stated, during the normal sintering process about one-half of the added silica is volatilised. By maintaining the ingot at a temperature of 3,300 deg. K. for 1 hour the whole of the silica can be volatilised. Metal L was prepared in this manner, by removing the silica from an ingot of metal J. The sodium content remains unchanged.

Metal M (0·35 per cent. Cs_2O, 0·7 per cent. ThO_2); *Metal N* (0·12 per cent. K_2O, 0·2 per cent. CaO, 0·7 per cent. ThO_2).—These metals were prepared in the same manner as the corresponding metals containing sodium, solutions of cæsium chloride and potassium chloride being used. The accuracy of composition achieved in the preparation of these metals was tested in nearly every case by making several independent batches. The characteristic structure of each metal, obtained on annealing, was always reproduced.

Mechanical Work on the Metals.—The usual methods of working tungsten were followed, and as accounts of this have been published, only the main points bearing on the discussion will be referred to. The grain growth phenomena which occur during sintering have been described by Jeffries. In these experiments all the metals were sintered under identical conditions of time and temperature, the fineness of the metal powder being controlled to give an ingot containing from 1,500 grains to 2,500 grains per square millimetre. The metal was then swaged to 0·7 mm. diameter, and thereafter drawn through dies to 0·04 mm. diameter. In the earlier stages of working the temperature of the metal was 1,650 deg. K., and the temperature was lowered progressively as the work proceeded. The whole reduction must be considered as cold-work, as there was no evidence of grain growth taking place at any stage. The reduction in area by this work was 99·997 per cent., which is very severe. The wire was then wound cold in spiral form on a mandrel 0·18 mm. diameter, and with a pitch of 0·055 mm. This was the form in which the wire was annealed in the experiments which follow. It is important to bear in mind that the material has undergone two distinct forms of deformation—first drawing (or shear) and second bending (compression and tension). The two deformations produce results on annealing which

* Abstract of a paper read before the Institute of Metals, on Wednesday, March 8.

are less marked in metal which had been drawn only, and will be referred to later.

Annealing.—The spiral wires were mounted as filaments in gas-filled incandescent lamps, and annealing was effected by applying a voltage to the lamp, sufficient to raise the temperature of the filament with extreme rapidity to 2,500 deg. K. This temperature was used throughout, and was selected because the particular effects under observation are more marked than at lower temperatures. It also eliminates the possibility of Jeffries' exaggerated growth due to temperature gradients since all parts of the wire are considerably above the "germinative" temperature. A series of filaments was made with each metal, and annealed for periods varying from a fraction of a second to 1,000 hours. Longitudinal sections of the spiral were then prepared in the manner described in a previous paper.* Such a series indicates the various stages in the development of the crystal structure.

Observations of Crystal Growth, General.—By this method of following crystal growth all that can be seen is the structure developed after a given time, under constant conditions. The actual growth or movement of boundaries cannot be observed, nor is it possible to mark a given area and photograph it at successive intervals in the manner developed so successfully by Carpenter and Elam. Owing to the extremely fine grain of tungsten wire, both after the final drawing and in the early stages of recrystallisation, no information concerning these steps has been obtained. In what follows the work of Carpenter and Elam, on the birth of new crystals, is accepted as fundamental, and applying equally to tungsten or to any other metal. It is assumed, therefore, that recrystallisation of the cold-drawn wire has taken place by the birth of new crystals in the grain boundaries, and their absorption of the old grain material; and that this has been followed by grain growth; but that both these processes proceed with such high velocity, and involve such minute crystals, as to escape observation in our experiments. A short account of the changes in crystal structure on annealing, in each of the metals will now be given.

All the wires have a very fine fibrous structure before annealing, and are indistinguishable from one another.

Metal A (99·95 + per cent. tungsten).—Grain growth takes place in the manner usually observed in metals, with gradual increase in the average grain size. Apparent equilibrium is attained after 24 hours, but movement of the grain boundaries is still taking place after 1,000 hours. By this time nearly all the crystals occupy the full cross-section of the wire, and there is a uniform tendency for them to be longer than their diameter.

Metal B (0·1 per cent. Al_2O_3, 0·1 per cent. SiO_2).—These small quantities of impurity do not materially affect the crystal structure. The metal is chiefly of interest in indicating the final distribution of the alumina. After burning 300 hours the wire becomes exceedingly brittle at the grain boundaries, even in the cold. This is due to the segregation of the impurities at the grain boundaries, and more particularly at the junction of several grains. These impurities are difficult to observe under the microscope, but their position can be determined indirectly. If the filament is heated to 2,500 deg. K., in the presence of phosphorus vapour, the alumina is reduced, and the phosphorus oxide and aluminium both volatilise. On polishing, black pits can be seen, which are found on etching to lie at the grain boundaries, and indicate the position occupied by the alumina. This is illustrated in Figs. 1 and 2, showing filaments annealed 600 hours with and without phosphorus vapour. The pits which are formed appear too large to be accounted for by the removal of the aluminium oxide only, and we have other evidence in support of the view that some tungsten volatilises after the pits have been once formed.

FIG. 3. METAL E. 0·25 PER CENT. ThO_2, 0·10 PER CENT. Na_2O.

FIG. 4. METAL F. 0·50 PER CENT. ThO_2, 0·10 PER CENT. Na_2O.

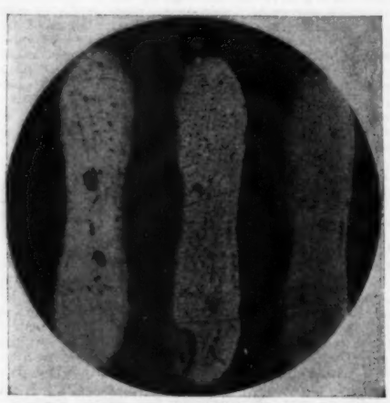


FIG. 5. METAL G. 0·75 PER CENT. ThO_2, 0·10 PER CENT. Na_2O.

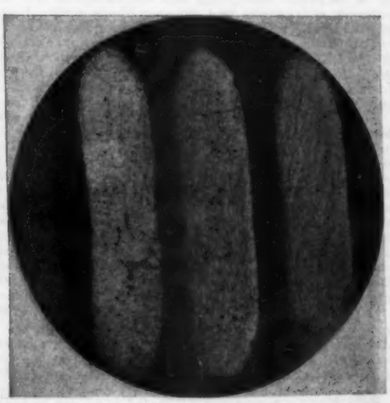


FIG. 6. METAL H. 0·75 PER CENT. ThO_2, 0·2 PER CENT. Na_2O.

SHOWING THE EFFECT OF ThO_2 AND Na_2O IN PRODUCING EXAGGERATED GROWTH IN TUNGSTEN ANNEALED FOR TWO HOURS. × 300.

Metal C (0·7 per cent. ThO_2).—A comparison with metal A, shows the restraining influence of thoria on grain growth, confirming the results of Jeffries. After annealing 1,000 hours, the metal still has a finer grain than pure tungsten annealed for 2 hours. The distribution of the thoria can be seen directly under the microscope in favourable circumstances. Thorium oxide is reduced by phosphorus in the same way as alumina. The metallic thorium is not volatilised appreciably, however, at this temperature. The reduction of the thoria is followed immediately by rapid grain growth, and the structure of pure tungsten is developed in a few hours. The metallic thorium probably alloys with the tungsten and offers no resistance to grain growth.

Metal D (0·7 per cent. ThO_2, 0·2 per cent. CaO).—The results obtained were identical with those described for metal C.

Metals E, F and G.—Very interesting results have been obtained with metals containing sodium, and it is the exaggerated grain growth which occurs in these metals that we wish chiefly to bring to notice. These three metals contain the same amount of sodium, and differ only in the thoria content.

Metal E (0·1 per cent. Na_2O, 0·25 per cent. ThO_2).—A grain growth velocity lying between that of pure tungsten, and tungsten containing 0·7 per cent. ThO_2 was observed. This would be expected from the slight resistance offered by the small amount of thoria. Fig. 3 shows this metal after annealing 2 hours.

Metal F (0·1 per cent. Na_2O, 0·5 per cent. ThO_2).—This metal exhibited the first signs of exaggerated grain growth. After annealing 1 minute, the majority of the grains are small. At irregular intervals, however, portions of the wire are found to consist of a single large grain occupying the whole cross-section of the wire. The average length of these crystals is about 10 times their diameter. Further annealing does not materially alter these, but the remaining structure becomes coarser. Fig. 4 shows the structure after 2 hours.

Metal G. (0·1 per cent. Na_2O, 0·75 per cent. ThO_2).—The exaggerated growth is much more marked in this metal. The structure which develops in the first minute, and does not alter appreciably on further annealing consists of patches of fine-grained metal separated by one or more long crystals. The average length of the long crystals in this metal is from 50 to100 times their diameter. Fig. 5 shows a portion of a single crystal occupying several turns of the spiral.

Metal H (0·2 per cent. Na_2O, 0·75 per cent. ThO_2).—The same structure develops in this metal after annealing 1 minute. The proportion of long crystals in the wire has increased, although they are not on the average longer than those in the last metal. The condition of apparent equilibrium is attained with extreme rapidity, and no subsequent grain growth, except for a slight coarsening of the fine material, is observed. The structure is shown in Fig. 6. In these metals, which rapidly develop long crystals, the thoria probably lies in the grain boundaries of the fine-grained material as before. The photomicrographs also reveal the presence of thoria distributed throughout the long crystals, where the particles appear as black specks. This is clearly shown in Figs. 5 and 6. On prolonged annealing these particles segregate in the boundaries, and presumably also at the surface of the wire, and the crystals appear much cleaner after burning 600 hours. That these specks are thoria is seen by comparison with a section of metal K in which the same structure is developed in the absence of thoria. The crystals in this case are perfectly clean and white.

Metal J (0·1 per cent. Na_2O, 0·2 per cent. SiO_2).—The structure developed is of the same type as in other metals containing sodium. The grains are in general considerably coarser, and the long crystals less easily distinguished, as their length is seldom more than four or five times their diameter.

Metal K (0·1 per cent. Na_2O, 0·4 per cent. SiO_2).—Increasing the amount of silica present in the metal favours the development of long crystals. In this metal single crystals are formed 300 times as long as their diameter in 1 minute, and the fine-grained material is reduced to a minimum. Photomicrographs show the very rapid development of this structure. Crystal growth has practically ceased after annealing for 1 minute.

Fig. 7 shows the structure of the fine-grained material at higher magnification, and the various orientations of grains can be seen from the etching effects. Fig. 8 shows the boundary between the fine material and a long crystal, only part of which appears in the photograph. Fig. 9 shows the junction between two long crystals. This is taken at a magnification of 1,500, and the different orientation of the two grains is seen from the etching pits. Fig. 10 shows a small grain enclosed in a long crystal. This is typical of these metals.

The silica in these metals lies in the grain boundaries. It has already been mentioned that some silica is volatilised during sintering. Volatilisation continues more slowly at the annealing temperature, but is almost complete after 600 hours, and results in the development of pits at the grain boundaries. The pits are developed in the absence of any reducing agent, and are therefore distinct from a similar appearance produced by the reduction of alumina.

Metal L (0·1 per cent. Na_2O).—The removal of the silica from the last metal destroys its power of exaggerated growth. With sodium oxide as the only impurity, a structure similar to that of pure tungsten is developed.

Metal M (0·35 per cent. Cs_2O, 0·7 per cent. ThO_2); *Metal N* (0·12 per cent. K_2O, 0·2 per cent. CaO, 0·7 per cent. ThO_2).—These metals are the same as metals C and D, but with the addition of an alkali. The development of the long crystals was well marked in both cases showing that both potassium and cæsium have the same effect as sodium in promoting exaggerated growth in the presence of thoria.

The Effect of Impurities.—General.—Looking at the results obtained on annealing the various metals just described, some broad generalisations may be made on the effect of different types of impurities introduced into tungsten.

Insoluble Impurities.—Thoria and lime have a definite restraining influence on grain growth. Metals containing these impurities exhibit very little grain growth after annealing for 1,000 hours, even under conditions when, in their absence, growth proceeds rapidly in the first hour. Alumina has the same effect to a less degree. Metal containing more than 0·2 per cent. of this oxide has been found difficult to work, and accurate comparison with thoria has not been made. Silica offers a still smaller resistance to grain growth. The restraining effect of these oxides is also shown in metals containing sodium as far as concerns those portions of them not occupied by long crystals. There is a gradual suppression of grain growth in the fine-grained material

* *Transactions of the Faraday Society*, 1921., Vol. xvii.

of metals E, F and G with increasing thoria. The same effect is found in J and K, with increase in silica. After annealing at the temperature used in these experiments, all these oxides are found to segregate at the grain boundaries, and more particularly at the junction of several grains. When long crystals are formed rapidly thoria remains for some time in the body of the crystal, but eventually moves to the grain boundaries. In this connection the statement of Carpenter and Elam that "in worked and annealed metals they [impurities] either pass into solution or remain scattered throughout the crystals quite independently of the [grain-] boundaries" requires modification. It would appear from our experiments that if annealing is carried out for a sufficient time at an elevated temperature insoluble impurities will eventually occupy the grain boundaries. These results are summarised as follows: (1) Impurities which remain undissolved in a metal segregate in the grain boundaries on annealing, provided sufficient time is given at a sufficiently elevated temperature. (2) The presence of impurities in the grain boundaries hinders crystal growth.

Soluble Impurities.—We now come to a consideration of those metals in which exaggerated growth takes place. All the metals in which long crystals are formed contain sodium, or one of the alkali metals. These metals combine with tungsten and oxygen to form "bronzes" which, it will be shown later, are soluble in tungsten. Exaggerated growth does not, however, occur when sodium alone is present. A second impurity, of the insoluble type, is also necessary.

The frequency with which the long crystals occur, and their length, depend both on the amount of sodium and on the amount and nature of the insoluble impurity. Metal L with sodium alone shows the structure of pure tungsten. Metal E, with 0·25 per cent. ThO_2, shows some restraint, but no long crystals. In F (0·5 per cent. ThO_2) the first signs of exaggerated growth occur. The crystals are not of great length, and the remaining grains are coarse. G (0·75 per cent. ThO_2) shows a further increase in both the length of the crystals and the fineness of the remaining grains. H contains the same amount of thoria, but twice as much sodium. The crystals are more frequent but of no greater length. The metals containing silica and sodium show the same progression. In J (0·2 per cent. SiO_2) the general grain size is large, and the long crystals only slightly developed. Increasing the silica to 0·4 per cent. in K results in a greatly increased length of crystal, and a corresponding fineness of the remaining grains. In general, increasing the resistance to grain growth favours the development of long grains. Jeffries found that increased restraint had a similar effect in promoting exaggerated growth when a temperature gradient was maintained, and it will be shown that the two phenomena are closely connected.

PART II.—THE VAPOUR PRESSURE HYPOTHESIS.

We find that tungsten containing both thoria and sodium develops long crystals on annealing, whilst a similar metal containing thoria only remains fine grained. The effect of strain will be omitted from the present discussion. The two metals were made and worked under identical conditions, and we shall assume the strains are the same in both. An observation which has already been mentioned is of fundamental importance in this consideration. In all cases where sodium has been present, minute crystals of tungsten bronze have been invisible in the metal powder. These crystals can be heated to a white heat in hydrogen without decomposition. By means of spectroscopic analysis we have found that the amount of sodium existing in the wire after annealing for 600 hours at 2,570 deg. K is the same within 10 per cent. as was present in the original metal powder. This is taken as evidence that the sodium remains in combination as tungsten bronze, as no other compound of sodium is known which would not volatilise under these conditions. The development of the long crystals points to the existence of small grains, or nuclei, with a power of exaggerated growth, being situated at intervals along the wire. The significant fact that these long crystals only develop in metals in which we have detected the bronze particles points to a possible connection between the two.

On sintering the ingot, the crystals of bronze are absorbed by the growing tungsten grains, forming solid solutions. We have not yet been able to identify these crystals at this stage, owing probably to the fact that both tungsten and bronze are extraordinarily resistant to ordinary etching reagents. As sintering is carried out 300 deg. to 400 deg. below the melting-point, diffusion will be slow, and owing to the inhomogeneity of the original powder there will not be a uniform distribution of solid solution. After drawing into wire, the first annealing produces a very refined structure, but the new grains will again vary in composition. Consider now one grain which contains a certain amount of bronze in solid solution, and is situated amongst grains of similar size, but of pure tungsten. These grains will have a definite vapour pressure, which is manifested by a tendency of the atoms at the surface of the grain to shoot off and "condense" or re-orient themselves on the adjacent grain. This conception of vapour pressure gives a physical significance to what is usually referred to as the "mobility" of the atoms of a crystal. When two crystals or grains in contact have the same vapour pressure, the transference of atoms is equal in each direction—that is, no appreciable grain growth occurs. This view of the transference of atoms is in conformity with the generally accepted idea of boundary migration as opposed to coalescence. Further evidence that grain growth is due to a process in every way analogous to distillation will be brought forward later in the paper.

The vapour pressure of a grain containing dissolved bronze will be less than that of a pure tungsten grain. More atoms will arrive at its surface from the tungsten grains in a given time than will leave it. In other words, the solid solution or "bronze grain" will grow at the expense of the tungsten grains. This process will continue, but at a continually reduced velocity as the concentration of the "bronze grain" is reduced by the absorption of pure tungsten.

At this stage another factor promoting exaggerated growth comes into play, namely, grain-size contrast. Although opinion is not unanimous on the effect of this, further evidence, both experimental and theoretical, will be produced later in the paper. In the meantime it will be assumed that large grains in general tend to absorb small ones. As soon as the "bronze grain" has absorbed some of its neighbours, its increased size alone will enable it to continue absorbing the small grains with which it comes in contact. This will proceed with increasing velocity until either (1) the growing grain comes in contact with another of similar magnitude, or (2) the resistance to grain growth offered by insoluble impurities is sufficient to check its progress. Both these conditions of apparent equilibrium are found. The part played by the insoluble additive, and the necessity for its presence, if exaggerated growth is to take place, is now clear. In the absence of a restraining additive, the small tungsten grains absorb one another with such rapidity that the "bronze grains" never attain a size sufficiently above the average for exaggerated growth to proceed appreciably. This was found in metal J, where the coarse grains developed by the weakly restrained tungsten were with difficulty distinguished from the slightly larger "bronze grains." The gradual transition is also observable in the series E, F, and G with increasing thoria. A similar phenomenon has been observed by Jeffries, who found that the formation of large crystals produced by "temperature" or "strain" gradients was accelerated by increasing the resistance to grain-growth. The view put forward may be summarised under: (1) Grain growth after recrystallisation takes place by a process analogous to distillation; (2) the growth of one grain at the expense of its neighbours will take place if its vapour pressure is lowered; (3) the lowering of the vapour pressure may be caused by a dissolved substance; (4) this process is exaggerated by the addition of insoluble substances which restrain the growth of the normal grains; (5) exaggerated growth continues because of the grain size contrast developed by the process.

The absence of similar observations by other workers on the effect of dissolved impurities in metals, in promoting exaggerated growth, at first appears remarkable. The explanation would seem to lie in the fact that all commercial metals, at some stage of their manufacture, are molten, and that variation in the composition of different crystals is thereby largely eliminated. The metals used in this research, on the other hand, were pressed from powder admittedly inhomogeneous, and the highest temperature subsequently reached gave no opportunity for complete diffusion. Whilst therefore, the hypothesis developed to account for what is probably a unique case will not find immediate application in explaining results obtained in other fields, it has led to the consideration of the whole question of crystal growth and recrystallisation from the new point of view of vapour pressure. This view has been extended to cover the wider field of recrystallisation and crystal growth after deformation under ordinary conditions; and the theory, in the light of which the results of other workers are reviewed, is put forward in the belief that although not fully established it affords a more complete and more consistent explanation of the known facts than has yet been given.

FIG. 7. FINE-GRAINED AREA. × 1000.

FIG. 8. JUNCTION BETWEEN A LONG CRYSTAL AND FINE-GRAINED METAL. × 1000.

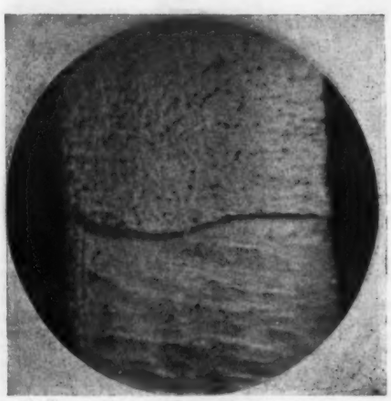


FIG. 9. JUNCTION BETWEEN TWO LONG CRYSTALS, SHOWING DIFFERENCE IN ORIENTATION. × 1500.

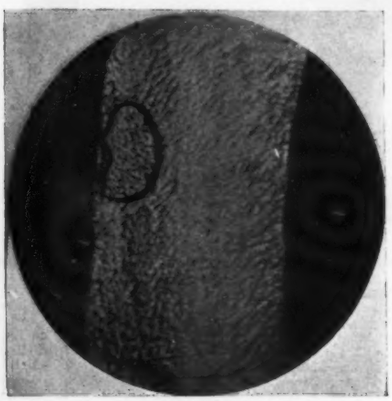


FIG. 10. SMALL GRAIN ENCLOSED IN A LONG CRYSTAL. × 1000.

TYPES OF STRUCTURE PRODUCED BY EXAGGERATED GROWTH IN METAL K (0·4 PER CENT. SiO_2, 0·1 PER CENT. Na_2O). ANNEALED ONE MINUTE.

PART III.—THE GENERAL THEORY.

1. *Introduction.*—Before discussing the theory, we wish to make quite clear that we adopt views in regard to several points on which we are aware that the opinion of metallographists is not unanimous.

The theory is based on an acceptance of the amorphous theory of Beilby, and some of the further developments of it by Rosenhain, Jeffries and others. This theory is so well known that it is unnecessary to give more than the main features which affect the argument. It rests on an assumption of the existence of a layer of amorphous metal between the crystal grains, and that plastic deformation increases the amount of this material between the grains, and also generates it at the places of slip within the crystals. These views appear to offer the best explanation of all the facts, and we believe that their further development in what follows serves to strengthen the evidence in their favour. The amorphous theory, however, has not yet led to a satisfactory explanation of the forces which are operative in producing recrystallisation and crystal growth, nor of the manner in which the energy of deformation which gives rise to growth is stored within the metal. The most recent work on recrystallisation and crystal growth is that of Carpenter

and Elam on aluminium, and the results of their experiments will be largely used in developing the theory, although we are not in entire agreement with the interpretation they put upon their results.

2. *Effect of Strain.*—The first question is whether, after a certain small deformation, it is the severely strained grains which grow at the expense of their less strained neighbours, or whether the reverse is the case. Carpenter and Elam have put forward the view that it is the more strained crystals which grow, though they consider that the other crystals must all be strained to some extent before they can be absorbed. Evans, in a discussion of their paper, opposed this view, and suggested that it was possible that the severely strained grains re-oriented themselves on the less strained grains. Carpenter and Elam do not accept this, and bring as evidence the fact that increasing the strain decreases the size of the crystals produced. It appears to us, however, that there is nothing in their experiments which is not as satisfactorily explained by Evan's suggestion as by their view. If we assume that the severely strained grain is absorbed by a less strained or unstrained neighbour, the same results would follow. If the strain is below a certain value, no grains are sufficiently strained to be absorbed. A slightly greater strain will produce a few grains sufficiently strained to be absorbed by a less strained neighbour. The large grain thus formed will absorb its smaller neighbours, in the same manner as the large grain which would be similarly formed if the reverse process took place. Increasing the strain increases the number of grains capable of being absorbed, with the result that the final structure will consist of more, and therefore smaller grains. There is therefore nothing in Carpenter and Elam's experiments in conflict with this view.

We have found moreover, that in many of the metals described in this paper, which show exaggerated growth, the length of the crystals formed in a given time is always much greater if grown in a spiralled wire than they are if the same wire is annealed without spiralling. If the strained crystals grow at the expense of the unstrained, the increased strain due to spiralling should increase the number of centres from which growth takes place and so make the crystals more numerous but shorter, contrary to what is found. On our theory the increased strain increases the number of absorbable crystals, the number of centres (being determined by constitution) remaining unaltered, with consequent increase in the rate of growth and final length of the crystals.

We agree with Evans suggestion that it is more likely that a properly oriented (unstrained) grain would force the disorganised atoms of a strained grain to conform to its orientation, than that a deformed and badly-oriented grain should be able to force the atoms of a more stable grain to adopt their orientation. Moreover, Carpenter and Elam do find that in order that a grain should be absorbed it must be strained to some extent. The unstrained grains at the shoulders of their test-pieces were, as a rule, not absorbed, or only with difficulty. There seems no reason why, if as they suppose it is energy stored in a strained grain that gives it the power of absorbing its neighbours, slightly strained grains should be more easily absorbed than unstrained grains. In fact, on their view, an unstrained grain should be more easily absorbed than a strained one. They are therefore forced to distinguish between a degree of strain which renders a grain easily absorbed, and another degree of strain which makes this grain capable of absorbing others. There seems to be no obvious physical basis for such a supposition.

For these reasons we shall, in what follows, adopt the view of Evans, that it is the less strained grain which absorbs its more highly strained neighbour.

3. *Grain Size Contrast.*—The second question is whether large grains normally absorb small ones, and if not, in what circumstances this may not be true. Jeffries considers that large grains absorb small ones as a rule, but believes that a definite "grain size equilibrium" exists for each temperature and degree of strain. Howe does not agree that this idea of equilibrium has been sufficiently proved, and maintains that true equilibrium should only be attained when the metal consists of a single crystal, or when an absolute identity of grain size exists. The majority of observers have agreed that large crystals do, as a rule, absorb small ones. At the same time, many cases have been observed in which a small grain exists enclosed by, or in contact with, a large grain, in apparent equilibrium. Carpenter and Elam point out that any satisfactory theory of crystal growth must take account of this.

From our experiments it appears that small grains may exist indefinitely in contact with large ones if: (1) They are surrounded by an envelope of insoluble impurity, or (2) If the vapour pressure of the small grain is lowered by the presence of a soluble impurity. The first case occurs frequently in commercial metals, and in tungsten of moderate purity. Jeffries has published an excellent photograph of a small grain of tungsten enclosed in a large one illustrating this case.

The metals containing sodium, described in this paper, show both types. The fine-grained portions in metal K exist indefinitely in contact with each other and with the long crystals, owing to the resistance to growth of the thorns. The long crystals, as already mentioned, also show a very large number of enclosed grains of moderate size. This is very seldom, if ever, observed in pure tungsten. All these conditions are illustrated in Figs. 7 to 10. These crystals probably contain dissolved "bronze" and were themselves growing when they were surrounded by the advance of the larger crystal, the tendency of the large crystal to absorb the small one being counterbalanced by the lower vapour pressure of the small crystal.

The only observed cases of small crystals actually absorbing large ones occur in strained metal, and are accounted for by a difference in strain between the large and small grains.

The fact that apparent equilibrium is attained even in the purest metals, such as the gold used by Rose, seems to be due to the extraordinary slow rate at which growth proceeds after the grain size has become large. It was shown in a previous paper* that although the grain size in metal B, after annealing 20 hours, had not visibly altered after 1,000 hours, there was evidence which showed that a movement of the grain boundaries had actually taken place.

The idea we wish to put forward, and which we believe accounts satisfactorily for the known phenomena of crystal growth, rests upon the hypothesis that all crystal growth occurs by a process of distillation. That is to say, that all crystals exert a certain vapour pressure, and that the vapour pressure of any crystal in a metal depends upon several factors. At the surface between two crystals there is a constant evaporation of the molecules of each crystal into the amorphous material between them and a condensation of molecules upon their surfaces. If evaporation takes place more rapidly from one crystal than from the other—that is, if their vapour pressures are not identical—more molecules will condense on the crystal of lower vapour pressure than will leave it. The crystal of low vapour pressure will grow at the expense of its neighbour of higher vapour pressure.

4. *Effect of Grain-Size on Vapour Pressure.*—This idea has already been elaborated in the case of the metals containing sodium, where there was evidence of a difference in composition producing a difference of vapour pressure among the crystals. It applies with equal force to the case of growth produced by grain-size contrast. The vapour pressure of a small crystal is greater than that of a large crystal. This has been proved both thermo-dynamically and experimentally by Pabloff. There is also a close analogy in the well-known fact that small crystals have a higher solution pressure than large crystals. In this connection we may quote the experiments of Rosenhain and Ewen on vacuum etching. They found that fine-grained silver lost more weight than coarse-grained metal on heating under identical conditions *in vacuo*. They attributed a part of the difference to the larger amount of volatile amorphous material in the fine-grained metal, but calculation showed that this could not account for more than a small proportion of the difference. In a metal, therefore, which consists of fine and coarse grains in contact, we may expect that when the temperature is raised the small grains will be deposited by a process of distillation on to the surface of their neighbours. It has been shown by Rosenhain, Jeffries and others that at low temperatures the amorphous material is very rigid. This would prevent any appreciable movement of molecules, or crystal growth at ordinary temperatures. As the temperature is raised the amorphous material rapidly softens, and at the temperature at which crystal growth occurs it is in a condition to allow of the rapid transference of molecules. It is not necessary to assume that the molecules from one crystal pass right through the amorphous material on to the opposite crystal. It is more probable that the molecules which are deposited come from the amorphous material itself, which is continuously replenished by volatilisation from the crystals. We should therefore expect, on the vapour pressure hypothesis, that large grains would absorb small ones on annealing. When the difference in size becomes small, growth will be so slow that apparent equilibrium is attained. The difference in vapour pressure of two small crystals whose diameters are in a given ratio can be shown to be greater than is the case for two large crystals whose diameters are in the same ratio. On this account growth becomes much slower at a given temperature as the grain size increases.

5. *Effect of Temperature on Vapour Pressure.*—The fact that after apparent equilibrium has been established at one temperature, growth proceeds again on raising the temperature, requires some explanation. If the vapour pressure of a pure substance is compared with that of the same substance containing a small quantity of soluble impurity, it is found in all known cases that the difference in vapour pressure increases as the temperature increases. If now we suppose that a certain difference in vapour pressure between two crystals is necessary to overcome resistance to grain growth, equilibrium will be reached when grain size contrast has been reduced to a value corresponding to this difference in pressure. At a given temperature, therefore, grain growth will cease when a certain grain size is attained. On raising the temperature of the metal the difference in vapour pressure between crystals will be increased and grain growth will proceed again until the pressure difference is reduced, and a new equilibrium grain size is reached. It is thus clear that for each increase in temperature, a corresponding increase in grain size will take place before apparent equilibrium is attained. In commercial metals apparent equilibrium will be attained with a large grain size contrast existing, owing to the high resistance of the insoluble impurities. The hypothesis appears to give a satisfactory explanation of the observed phenomena of grain growth in relation to grain-size contrast.

6. *Effect of Strain on Vapour Pressure.*—We now come to the case in which grain growth takes place after a certain strain insufficient to cause recrystallisation, as in the experiments of Carpenter and Elam on the production of single crystals in aluminium. One of the difficulties encountered in previous theories is the explanation of how the energy which produces growth on annealing is stored in the strained metal. It does not appear possible that it can be stored in the amorphous material, for, as Carpenter and Elam have pointed out, softening can be completed without destroying the power of growth at higher temperatures.

By analogy with the grain growth which occurs when grain-size contrast, or varying composition, exists, it seems likely that the force which produces growth on annealing after strain must be of the same kind. Have we any basis for assuming that a strained crystal has a higher vapour pressure than an unstrained crystal? We have already stated the arguments on which we base the view that it is the unstrained crystals which grow at the expense of the strained. We have at present no evidence as to the arrangement of the molecules within a strained crystal. Until such evidence is forthcoming, we cannot do more than suggest what may be expected to occur. When a metal is strained the external form of the crystals is changed by a transference of blocks of crystal material along planes of slip. Amorphous material is generated at these planes, and at the grain boundaries. It seems probable to suppose, further, since the crystals of a metal are elastic, that the molecules of the crystal are also slightly distorted from their space lattice. If this distortion exceeds a certain amount—in other words, if the stress is greater than the elastic limit—blocks of crystal material will move bodily, either by twinning or more usually along slip planes. In general, however, after a given small strain a number of crystals will probably have their molecules slightly disarranged. Some interesting photographs of twisted single crystals, by Jeffries, do show a gradual change in orientation, along the crystal, showing that the strain is not entirely taken up by slip along gliding planes, which would preserve the original orientation completely.

The formation naturally taken up by the molecules in a crystal is one which satisfies to the maximum degree their mutual attraction. Any distortion from this natural crystal lattice will lessen the forces acting on the molecules tending to hold them in place. The vapour pressure of a crystal depends on the forces acting between the molecules tending to retain them in position, and the amplitude of vibration which tends to separate them. When the vibration is great it may be sufficient to overcome the mutual attraction, and a molecule leaves the surface. As the temperature of a crystal is raised this condition becomes more frequent, and the number of molecules leaving a unit area of surface in a given time increases.

If this is a true picture of what is taking place at the surface of each crystal, and accounts for increasing vapour pressure with rise of temperature, the same effect should be produced by altering the forces holding the molecules together. If their normal and most stable spacing is distorted by straining the crystal, as we suppose, the forces holding them together will be reduced, and for the same temperature the vapour pressure of that crystal will be higher. Whether this is actually the case will, we hope, be determined either by X-ray analysis or by direct vapour-pressure determinations. If, in the meantime, this is accepted as a working hypothesis, it becomes possible to account for some of the facts of crystal growth.

7. *Effect of Slight Strain.*—If a metal is strained to a small amount, slip bands and twins which are formed disappear on annealing and no growth takes place. In this case it appears that the distortion of the crystals does not lessen the attraction between the molecules sufficiently to produce the necessary difference in vapour pressure for appreciable growth.

8. *Effect of Critical Strain.*—A further strain distorts a few crystals the required amount. Their vapour pressure is raised and their molecules are deposited on a neighbouring unstrained grain. The grain thus formed has a reduced vapour pressure, owing to its size, and absorbs its smaller neighbours. The smaller the strain, provided it is above the minimum required, the fewer crystals and the larger their ultimate size. A greater strain produces a greater number of unstable grains, and hence more, and smaller, final grains. Degrees of strain falling within this range have been referred to as critical strain by previous workers. Carpenter and Elam have shown that the greater the strain the lower the temperature required to produce grain growth. This would naturally follow since the factors which increase the vapour pressure of a crystal are: (1) Higher temperature, (2) lesser mutual attraction.

If the mutual attraction is lessened by great distortion, then it is unnecessary to raise the temperature so high as would be necessary if the mutual attraction were but slightly impaired.

9. *Effect of Severe Strain.*—Turning now to the case of recrystallisation which occurs on annealing a metal strained to a greater degree than in the cases we have just been considering. On the hypothesis that it is the strained grains which grow, it is difficult to see why too great a strain should cause an entire recrystallisation, rather than that some of the severely strained grains should grow. To support this we should have to postulate yet a third degree of strain which again prevented growth. If, on the other hand, we are right in assuming that it is the unstrained grain which grows, we should not expect growth to occur in a severely deformed metal in which no unstrained grains remained. The degree of strain will tend to be a maximum in all the grains, and any degree of strain above this will have been relieved by slip. If differences in strain occur they will be small and unlikely to produce much growth. It was noted by Mathewson and Phillips, and has since been clearly shown by Carpenter and Elam, that the new crystals are born in the grain boundaries, or in the twinning planes. During the deformation, when the crystal surfaces were being rubbed against one another, it is probable that small crystalline fragments are detached and become embedded in the amorphous material, being thus protected from further distortion. This view was put forward by Beilby.

These small fragments, being probably unstrained,

* *Transactions of the Faraday Society*, 1921, vol. xvii.

will, on annealing, grow at the expense of the amorphous material surrounding them in the first instance, and subsequently at the expense of the strained mass of the metal. We should thus expect that in a metal in which no unstrained grains remain growth would take place around any small fragments which had escaped deformation, and these would chiefly exist in the amorphous material at the grain boundaries. In certain cases we might also expect another factor to come into operation which would assist this process, though to what extent it is universally true is doubtful. It has been shown that in the case of tungsten the impurities tend to segregate at the boundaries. This is also true of eutectics, and other solid solutions, in many of the common metals. Carpenter and Elam, in accounting for their etching effects, suggest that "the first crystals to separate will be purer." It seems more probable however, that as these new crystals are formed in the old grain boundaries, where in many cases the impurities are most concentrated, they will tend to absorb these impurities during their growth. If this should happen their vapour pressure would be lowered and a still greater contrast with the strained grains of high vapour pressure would be obtained, thus favouring more rapid growth. The inclusion of thoria within a single crystal of tungsten during the stages of rapid growth has been demonstrated, although it does eventually migrate to the grain boundaries.

10. *Effect of Temperature Gradients.*—There is another well-known type of exaggerated grain growth that falls in with the hypothesis. Jeffries has shown that exaggerated growth may take place when a tungsten slug is heated by the passage of an electric current. With a suitable current a temperature gradient from the centre to the outside of the metal is obtained, which produces a ring of coarse grains, the grains on either side remaining fine. On continued heating the coarse grains finally absorb all the fine grains in the centre, the colder surface of the slug remaining fine grained. Jeffries explains this on the hypothesis of a "germinative temperature," grains below this temperature being unable to grow. Grains at the germinative temperature are able to absorb colder grains in contact with them, and this is followed by the absorption of the central grains.

This idea is not convincing. It offers no clear conception of the forces which bring about crystal growth, or of the actual mechanism of growth, and it involves the assumption that a grain, which is too cold to grow, may be absorbed by a hotter, and therefore less stable grain, of similar size.

The explanation we would put forward follows naturally from the vapour pressure hypothesis. Near the surface of the ingot the vapour pressure of the grains is too low to overcome the resistance to growth. Nearer the centre there will be a point at which the difference in vapour pressure between two grains will be sufficient to overcome the resistance, which will be reduced by the higher temperature. The colder grain will then absorb the hotter grain of higher vapour pressure, this being the reverse of what Jeffries has supposed to take place. The large grains thus formed will then absorb the central ones, where exaggerated growth has not taken place on account of the more uniform temperature. On this hypothesis Jeffries' "germinative temperature" is the temperature at which the difference in vapour pressure between two grains is sufficient to overcome resistance to growth.

In general, therefore, the germinative temperature of any particular metal will depend on the distribution of impurities, the temperature, and the degree of strain, which may all affect the differences in vapour pressure existing between the crystals.

ZINC PRODUCTION IN THE UNITED STATES.—Plans have been formulated by the United States Bureau of Mines for a complete survey of the milling problems of the tri-State district of Missouri, Oklahoma, and Kansas, with the object of improving the recovery of zinc in the mills. Other problems that may be considered are the recovery of zinc from tailings, determining the amount of sphalerite made excessively fine by the blasting, and removing lead from the "flotation zinc." This work is being conducted in co-operation with the Missouri School of Mines and Metallurgy. At a conference held in St. Louis, between representatives of the Bureau of Mines and operators of the Mississippi Valley lead and zinc fields, for the purpose of formulating a detailed programme for the Mississippi Valley experiment station, it was brought to the attention of the bureau that zinc was being encountered in increasing amounts in the fluorspar ores of southern Illinois and Kentucky. The ordinary treatment by jig and table concentration results in a considerable loss of fluorspar, and zinc cannot be removed by this method, because the zinc and the fluorspar differ so little in specific gravity. Experiments at the station resulted in developing two improved methods. One employing electrostatic separation, takes out the lead, gives a marketable zinc concentrate and also a spar product of practically any grade desired—99 per cent. calcium fluoride having been made in the tests. This fact makes possible the production of acid spar (98 per cent. CaF_2) from the gravel spar (85 per cent. CaF_2) now produced. Acid spar commands a much higher price than gravel spar. The second method employs flotation. Tests give a higher recovery of zinc than was obtained by electrostatic separation, but the spar product is lower grade and finer grinding is necessary. The method, however, is a great improvement over earlier methods, and as compared to electrostatic treatment is preferable in stormy weather. A large company, whose representatives assisted in the tests, has adopted it for treating this type of ore.

DROUGHTS AND FLOODS.

SIR NAPIER SHAW, F.R.S., dealt with the very imperfectly understood meteorological features of the phenomena of "Droughts and Floods" in the two lectures which he delivered before the Royal Institution on Thursdays, February 2 and 9. He confined himself to the dependence of droughts and floods, both of which are extremely uncommon in this country, upon rainfall. Meteorologists best defined, he said, droughts (or floods) as a deficiency (an excess) of rainfall sufficient to cause serious economic consequences, though numerical values were sometimes attached to the definition. Areas bordering upon arid lands, in which the average annual rainfall was about 10 in., were most liable to droughts. Good wheat crops required about 20 in.: the average for England was 40 in., which fell on the western border of the country, whilst London received about 23 in. of rain. In 1921 the deficiency amounted to 13·7 in. in the South-East of England, to 10·3 in. all over England, and to 6·37 in. in Ireland, whilst Scotland, also dry in that summer, finally wound up with an excess of 2·95 in.

As regards the connection with other meteorological data, the distribution of the atmospheric pressure afforded the best guidance. In July last, and more or less throughout the summer, there were three high pressure areas in the Atlantic, west of Spain, about the North Pole and in the northern Pacific; and these "highs" were inter-connected in Europe by a cantilever or corridor along both sides of Scandinavia, in which the circulation was northward in the West and southward in the East. That corridor proceeded further on either along the south of England and the Channel or to the north or south of that path, and these changes were more difficult to account for than the persistency of the drought. Both the highs sent out tongues of high pressure, and in those corridors there was no rain. Wherever rain fell, the air was ascending. But it rose only to a height of about 6 miles, and we did not understand how it descended again. On the surface the wind passed, not from high pressure to low pressure across the isobars, but rather along the isobars in such a way that the "low" was on the left. If we could prepare a kinematograph series of weather charts, we could follow the changes of the weather.

Floods, Sir Napier stated in the second lecture, depended, of course, as much upon surface drainage as upon the actual rainfall. Thus floods were unknown in Cherraponjee, in the Khasi hills of Assam, in spite of their 30 ft. of rain per year. The two recent English rain floods of Norwich and of Louth (Lincolnshire) were typical. At Norwich 8 in. of rain fell in less than 24 hours on August 25, 1912; there was an area of very low pressure east of Norwich which by the next day had moved out into the North Sea. At Louth nearly 5 in. fell in 3 hours on May 29, 1920: there was no cyclonic depression in the neighbourhood, but a thunderstorm and violent upward air currents accompanied the disastrous flood. The air could only carry a certain amount of water vapour, equivalent to 2·87 in. in the tropics, and to 1·38 in. in England. When the air was forced up in some way, the water condensed, and when the convection currents were strong, the water drops might sink and be lifted again several times, finally to come down in big drops or as heavy hail stones. At Norwich the convection was tubular, the air rushing in more or less radially from all sides on the Earth's surface and lifting the actual local column of air like a piston. At Louth the convection was penetrative, the air rising by its own movement at rates of up to 66 ft. per second. That latter case was common in the tropics, but very rare here. It was difficult to understand how the core of the air column was removed, though we could imagine how the convergent flow from underneath would fill up the emptied core of a cyclonic low.

How a cyclonic disturbance with tangential inward flow could be set up Sir Napier Shaw demonstrated finally with the aid of a model consisting of a horizontal cylindrical box, a few inches in height, the periphery of which was formed of a series of vanes set in water-wheel fashion. The vertical axis of the cylinder was formed by a short glass tube through which a current of air was blown upward; the smoky air inside the box was then thrown into vortex motion. That model was based upon Lord Rayleigh's dynamics of revolving fluids, and in our atmosphere the spin was set up by the rotation of the Earth. But we knew too little about the circulation in the upper atmosphere and the way in which the air descended again after rising to explain the phenomena.

DANISH SHIPBUILDING COMPANIES.—Burmeister and Wain's Shipbuilding Company has had a satisfactory year during 1921, the surplus, including balance carried forward from the previous year, amounting to 7,528,046 kronen. The dividend has again been fixed at 12 per cent., as was the case for the preceding year, when the surplus was about 10,000,000 kronen. A sum of 1,000,000 kronen has been added to the reserve fund, which now amounts to about 10,000,000 kronen; 440,000 kronen has been carried forward, 250,000 kronen added to the workmen's fund of the company's pension scheme, 2,000,000 kronen set aside for reconstruction of slips, &c., and 1,500,000 kronen reserved to meet taxation. The Elsinore Iron Shipbuilding Company is about to extend its plant and buildings considerably. It can at present build vessels up to 400 ft. length and has so far delivered a total of 162 vessels, 109 for home service and 53 for foreign clients. The vessels include 6 ferry steamers and 22 ice-breakers, as well as a number of salvage steamers, and other special craft. The yard is satisfactorily employed at present.

CATALOGUES.

Portable Drilling Machine.—A special catalogue to hand from Messrs. William Asquith, Limited, Halifax, describes a portable drilling machine. This machine, which was fully described on page 304 of Vol. cx, enables holes to be drilled with the drill horizontal or vertical, or at any other angle, and with the drill working downwards or upwards. In constructional work, boiler-making and the erection of heavy machinery, this machine will do much work often done by hand, and its use often avoids the necessity for moving heavy pieces to a fixed drilling machine. The base is mounted on four wheels, and four screw jacks are provided to enable the machine to be levelled up on a wider base than that formed by the wheels.

Turbo-Compressors and Exhausters.—A series of turbo-compressors, exhausters and blowers, mainly for large volumes, and suitable for supplying air motors, blowing furnaces, gas boosting, grain elevating, &c., are described and illustrated in a special catalogue to hand from Messrs. Reavell and Co., Limited, Ipswich. By improved design of the diffuser blades fixed in the stator these machines have been made especially suitable for use where heavy fluctuations have to be provided for. Steam turbine drive is recommended where possible, but electric driving has been adopted in many cases, the motor and machine being fixed on the same baseplate. The illustrations in the catalogue are chiefly of units constructed for special purposes and cover a wide range of volumes and pressures.

Powdered Coal.—A description of the plant and a good deal of general technical information on the preparation and firing of powdered coal is given in a catalogue issued by the Hardinge Company, 120, Broadway, New York, who make a special study of the design and operation of such plant. It is quite truly stated that many experiments in burning this fuel have been abandoned without really exhaustive trial; but at the same time the mechanical difficulties are now rather overstated. Much of the elaborate conveying system would be equally necessary for firing ordinary coal. The catalogue gives more than usual attention to the advantages of quick and accurate adjustment of feeding the fuel—a point on which powdered coal might be made to rival oil or gas fuel, or very nearly so. The smaller size and cost of the stoking plant might also be more fully considered, but no great saving in total working cost of firing has been made out for powdered coal. The cost per ton of preparing and firing powdered coal has been given as 1·31 dols. (see ENGINEERING, vol. cxii, page 204), including capital costs. This would have to be compared with the cost of unloading, conveying and machine stoking ordinary coal. The catalogue is certainly a valuable contribution to the available information on the subject.

THE LARGEST MOTOR LIFEBOAT.—The Royal National Lifeboat Institution has completed the plans of the largest motor lifeboat in the world. Her length is to be 60 ft., with a 15-ft. beam, a draught of 4 ft. 6 in., and a displacement of about 40 tons. She will be fitted with twin screws, driven by two 75-h.p. motors specially designed by the Institution. In addition, she will have an auxiliary rig of one mast, carrying a small triangular forelug and jib. She will have a speed of about 9 knots to 10 knots and a radius of action of 100 miles. The new craft will be practically unsinkable. Each motor will be in a separate watertight compartment. There are to be two cabins, one forward and one aft, to hold 50 passengers, while the total number able to be taken on board will be over 150. The first boat of the type will be built for New Brighton, on the Mersey, to take the place of the present steam lifeboat, the Queen, and is now under construction.

THE BRUNE-HORST PEAT PRESS.—In the peat-pressing process of the engineers Brune and Horst, which is being tried in an experimental plant at Uerdingen, Rhenish, Prussia, the wet peat is mixed with about half its amount of dried peat and then submitted to a strong pressure in presses of a peculiar construction. The wet peat is received in a pit. From the pit it is taken by a belt conveyor to the disintegrator, which tears the fibre without compressing it, and is then delivered in a thin layer on another belt conveyor which had previously been covered with the dried peat. The wet and dry peat are mixed in a drum, and the mixture is charged by the aid of a bucket chain and another belt conveyor, into the presses. These consist of three flat rings (tables), 12 m. and 3·5 m. external and internal diameters, each ring bearing 48 radially-arranged pressure boxes. In each box two plungers are so geared that, as the table turns about its vertical axis (the tables run on circular rails) once in 6 minutes, each pressure box, which is square in section, is once charged and emptied. The charging is effected from above on the inner side of the table. As the table turns the plungers move first outward closing the charging ports and pushing the peat before them, and then approach one another and force the water out through the perforations of the wall of the boxes, until a cake of peat containing about 50 per cent. or 60 per cent. of water is delivered upon a belt conveyor passing underneath the tables. Part of this peat is fired directly or coked, or disintegrated and compressed again if still too wet. Another part of the peat coming from the presses is once more disintegrated and taken through a tubular drying chamber in which the water percentage is lowered to 30 by the waste heat of the engine; this peat, having been ground, forms the dry peat powder which is mixed with the original wet peat. The process is also applied to coal mud and coke dust. The pressure in the boxes is raised to 30 atmospheres.